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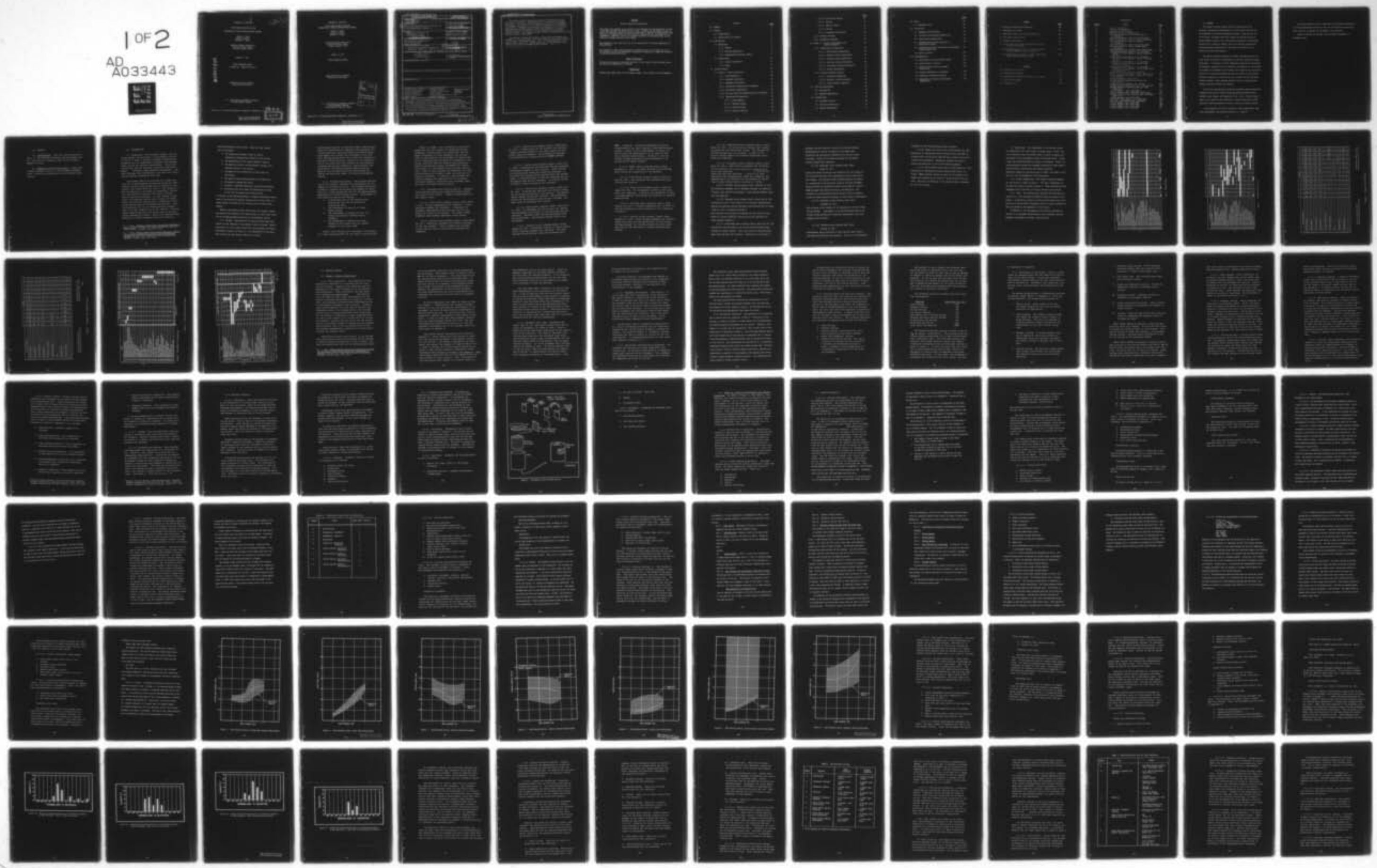

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REPORT NO. 675/AA-49

PILOT PLANT FACILITY FOR THE PRODUCTION OF TRITIUM RADIOLUMINOUS SOURCES

Robert J. Doda*
Harry H. Dooley
Marshall W. McCoy

American Atomics Corporation
425 South Plumer Avenue
Tucson, Arizona 85719

August 31, 1976

FINAL TECHNICAL REPORT
Contract No. DAAK02-74-C-0147

Approved For Public Release
Distribution Unlimited

U. S. Army Mobility Equipment Research
and Development Command

*Now with U. S. Nuclear Regulatory Commission, Washington, D. C.

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limited production	laser sealing	soak test
facility organization	semi-automatic production system	
glass shaping	process sequence	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides complete details concerning the construction, optimization and operation of a pilot plant facility for the production of tritium radioluminous sources. These sources are of the sealed, all-glass type which contain tritium gas and an internal phosphor coating. The facility has a capability of producing sources with a variety of shapes, sizes, and activity contents and provides advanced capabilities in the areas of reliability, uniformity and productive capacity.

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The report contains information on Phase I (Construction of the Pilot Plant) and Phase II (Optimization of the Pilot Plant and Limited Production). All aspects of actual experience gained in the obtainment of equipment, construction of the facility, optimization of the facility with respect to equipment and procedures, and production of a specified quantity of tritium radioluminous sources are covered in this report. The major operations of this facility are divided into the following primary sections: glass shaping, phosphor coating, radioactive gas filling, auxiliary sealing, and testing.

The facility optimization procedures determined system operational parameters and physical bounds concerning tritium activity levels, volumes, sizes, shapes, and production rates. Also, critical adjustments in the operation were identified. Limited production (11,900 specified tritium radioluminous sources) ~~verified the above results~~. established the operational procedures.

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Disposition

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1.0 SUMMARY

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The facility optimization procedures determined system operational parameters and physical bounds concerning tritium activity levels, volumes, sizes, shapes, and production rates. Also, critical adjustments in the operation were identified. Limited production (11,900 specified tritium radioluminous sources) verified the above results.

A time schedule for project completion, plant organization, manpower requirements, and problem areas also is reported.

The target production rates, specified in the purchase description, of 300 non-pressurized sources per hour and 30 pressurized sources per hour, were met or exceeded in all phases of the operation.

Lastly, a section is included which provides information on equipment costs.

2.0 PREFACE

2.1 Authorization. This work was authorized by the U. S. Army Mobility Equipment and Development Center, Fort Belvoir, Virginia, under Contract Number DAAK02-74-C-0147.

2.2 Number and title of DA project. Number MMT 7753509 (TROSCOM), Type III, FINAL TECHNICAL REPORT. Title: Production Technology for Self-Luminous Light Sources.

3.0 INTRODUCTION

3.1 Background. This document reports, in a detailed manner, the conclusion of intermediate efforts by the U. S. Army to provide a domestic manufacturing capability for the production of gaseous self-luminous light sources for military applications. These light sources are used for reliable, long-lived, self-energized, low-level light emission requirements. Compass lighting, dial illumination, and level vial lighting are several examples of such uses.

The present effort was preceded by a design contract for a semi-automatic production system for radioluminous sources (this design work is detailed in two reports, both dated March 30, 1973).[1] The design provided for advances in the areas of reliability, uniformity, and productive capacity over that of current state-of-the-art techniques. It also covered a capability of producing sources with a variety of shapes, sizes, and activity contents plus a capability of producing pressurized and non-pressurized sources. Also, the production rate of the design facility exceeded that of current capabilities in the industry. The completed engineering study and design report contained design drawings and factual data on the manufacturing methods for a semi-automated production system for

[1] R. J. Doda, Automatic Production System for Radioluminous Sources, 472/AA-41-4, American Atomics Corporation, Tucson, Arizona, March 30, 1973.

R. J. Doda, Safety Hazard and Hazard Evaluation Report for Automatic Production System for Radioluminous Sources, 472/AA-41-3, American Atomics Corporation, Tucson, Arizona, March 30, 1973.

sealed radioluminous light sources. Among the items covered were the following:

1. The shaping and molding of glass to various geometrical configurations required for the sources,
2. The adaptability to fill various shapes of sources,
3. The means to provide a uniform phosphor coating on the internal surfaces of the sources,
4. The means for the introduction of tritium gas into the sources,
5. The means for gas filling pressures of 300-1900 torr,
6. The method of sealing the source,
7. A method to determine adequacy of the sealing techniques,
8. Production rates of at least 300 unpressurized sources per hour and 30 pressurized sources per hour.

In addition to the engineering design, a complete radiological safety study of the system was prepared concerning the critical areas, inherent hazards in design, and the criteria used to control these hazards.

Based on the design contract effort above, the present contract was initiated and resulted in the construction of a pilot plant facility for the semi-automated production of radioluminous sources.

3.1.1 Purpose. The purpose of the project covered under this contract is the completion of two phases of work as follows: Phase I-construction of a pilot plant facility for the production of tritium radioluminous sources, and Phase II - the optimization of this pilot plant facility and the limited production of tritium

radioluminous sources, as specified. Phase I covers the purchase and installation of components and equipment into a pilot production line which meets the manufacturing requirements and includes the development of an auxiliary sealing system which uses a laser for sealing tritium self-luminous sources. Phase II is the optimization of the pilot plant and includes the determination of system operational parameters, system controls and limitations, and defines manufacturing tolerances. Phase II also includes production and delivery of a limited and specified number of tritium radioluminous sources.

3.1.2 Purchase Description. The purchase description of the contract contains the requirements for the completion of Phases I and II. The purchase description of Phase I required the purchase and assembly of equipment into a pilot production line for the semi-automated production of tritium luminous sources. Requirements of the production line are as follows:

1. A production rate of 300 unpressurized sources per hour and 30 pressurized sources per hour.
2. The development of methods to shape glass sources.
3. The development of methods to coat uniformly the internal surfaces with a phosphor.
4. The development of methods for laser sealing of all sources with an outside diameter of less than 4.5mm.

Phase I also required the development, if feasible, of a laser-sealing method for non-linear tritium sources.

Phase II covered the optimization of the pilot production line with respect to system operational parameters, system control and limitations, and the proper adjustment of these parameters and controls. Phase II also required the development of quality control of manufacturing tolerances for dimensions, luminosity, and other specific quality characteristics. Liquid scintillation testing procedures for completed sources is a requirement of the purchase description. Phase II also required the production of 11,900 tritium sources with shapes, sizes, and activity contents, as specified. In addition, the purchase description required the completion of the following: Instruction Manuals, Production Plan, Drawings, Data and Lists, and Final Technical Report.

3.1.3 Progress/status meeting reports. Progress/status meeting reports were submitted monthly during the course of this project. Summary accomplishments of each report follow.

3.1.3.1 First letter progress report, dated March 1, 1974. Project organization was completed. A work task/time schedule was completed. A timetable for equipment order/delivery was developed and was used during the course of the project. All items of major equipment, with primary importance, were ordered.

3.1.3.2 Second letter progress report, dated March 28, 1974. Additional equipment was ordered according to the time schedule. Laser equipment was received. Initial quality control outline and procedures were completed.

3.1.3.3 Third letter progress report, dated April 28, 1974. A plant layout of the facility was completed. A small prototype device for the laser sealing of non-linear tubes was designed. Requirements for drawings were determined in conjunction with USAMERDC personnel.

3.1.3.4 Fourth letter progress report, dated June 7, 1974. A meeting was held with Fort Belvoir personnel concerning the status of this contract. Laser sealing of rotating glass tubing was tested and accepted. A prototype non-rotating laser sealing device was manufactured. A production plan outline was developed and was reviewed by Fort Belvoir personnel. An overall outline of quality control procedures was developed.

3.1.3.5 Fifth letter progress report, dated June 28, 1974. A meeting was held with Fort Belvoir personnel to discuss the status of this project. The quality control manual outline was reviewed. The preliminary outline of the production plan was also reviewed. All major items of equipment were ordered.

3.1.3.6 Sixth letter progress report, dated July 31, 1974. All equipment for the facility was ordered. The preliminary first draft of the production plan was completed. Extensive laser sealing development work was accomplished. Unacceptable drawing quality was determined.

3.1.3.7 Seventh letter progress report, dated August 28, 1974. Operational testing of liquid scintillation counting equipment was completed. The laser sealing of non-rotating tubing was discussed with

MERDC personnel. Extensive experimental work was accomplished on the laser sealing of non-rotating glass tubing. A delay in the accomplishment of Phase I of this contract was determined to be at least 45 days due to facility modifications. Delivery of the two tritium filling machines was also determined to be several months behind schedule.

3.1.3.8 Eighth letter progress report, dated September 27, 1974. The laser sealing of non-rotating glass tubing was demonstrated to be feasible.

3.1.3.9 Ninth letter progress report, dated October 28, 1974. The luminance test equipment was manufactured and operated.

3.1.3.10 Tenth letter progress report, dated November 29, 1974. The preliminary outline of the final report was completed. A delay in the completion of Phase I of approximately three months was noted due to facility modifications.

3.1.3.11 Eleventh letter progress report, dated January 10, 1975. A revised completion date of April 30, 1975 was requested by the contractor for the completion of Phase I.

3.1.3.12 Twelfth letter progress report, dated February 10, 1975. Glass blowing equipment was received. Visits were held with the manufacturer of the tritium filling equipment for familiarization with this equipment and for the discussion of related operating procedures.

3.1.3.13 Thirteenth letter progress report, dated March 10, 1975. All utilities and systems were completed except for the ventilation system. The six-position tritium filling unit was received. A draft of the quality control manual and standard engineering procedures was completed.

3.1.3.14 Fourteenth letter progress report, dated April 10, 1975. Glass working equipment was installed. The six position and sixteen position tritium filling units were installed. A draft of the production plan was completed. A fixture for laser sealing of non-rotating glass tubing was completed, and demonstrated to be feasible for the sealing and separating of glass tubing without rotating the tubing.

3.1.3.15 Fifteenth letter progress report, dated May 10, 1975. The ventilation equipment and all equipment necessary for completion of Phase I were received and installed. Laser sealing equipment items also were installed.

3.1.3.16 Sixteenth letter progress report, dated June 10, 1975. Following the visit to this facility by the Technical Representative approval was received from the Principal Contracting Officer, by letter of May 23, 1975, to proceed with Phase II.
Work continued on the testing of equipment and the training of personnel for various operations associated with the fabrication of items required in Phase II.

3.1.3.17 Seventeenth letter progress report, dated July 10, 1975. Preliminary tests were begun on the tritium filling machines using hydrogen for system checkout. Tests were started on effecting glass seals using the laser seal technique. Malfunction of two pieces of

equipment occurred resulting in delays in obtaining luminance measurements and testing of integrity of the glass seals. Tritium gas was received and transferred into the AAC storage containers. Drafts of the Production Manual and the Quality Assurance Manuals were completed.

3.1.3.18 Eighteenth letter progress report dated August 11, 1975.

During this period tritium gas was introduced into the 6-position and 16-position machines with radioluminous sources fabricated on both systems. The testing of laser sealing equipment was halted by a malfunction in the electrical system of the laser equipment. During the month the operational status was reviewed by a team of MERDC personnel including the technical representative. The discussions covered manufacturing and quality control procedures as well as items relating fulfillment of other contract requirements.

3.1.3.19 Nineteenth letter progress report dated September 10, 1975.

Work continued on the checkout of all subsystems in the two tritium filling systems. Replacement of the malfunctioning items in the tritium filling machines and a defective transformer in the laser equipment were initiated.

3.1.3.20 Twentieth letter progress report dated October 10, 1975.

Radioluminous source prototypes of items required under contract item 0002 were fabricated and evaluated. Testing of replacement

equipment for the tritium filling systems continued.

3.1.3.21 Twenty first letter report dated November 10, 1975. Manufacture of radioluminous sources required under item 0002 was initiated after the prototype items had been evaluated and found to conform with requirements. Replacement equipment was found to function satisfactorily in the tritium filling equipment.

3.1.3.22 Twenty second letter report, dated December 10, 1975. Fabrication of radioluminous sources required under item 2 continued. MERDC personnel visited the plant for the purpose of reviewing work progress and the status of various items on the contract. The notice of extension of the completion date to December 22, 1975 was received.

3.2 Organization. The requirements of the contract called for completion of all tasks within a 20-month period. Phase I was to be completed within nine months, Phase II within 15 months, and the balance of the requirements within the 20-month period. Figure I shows the interrelationship of contract requirements. Phase I includes equipment purchase and equipment installation, while Phase II includes facility optimization and limited production.
Authorized changes for completion dates of Phase I and Phase II were April 30, 1975 and December 22, 1975 respectively.

3.2.1 Project organization. The original time/work schedule for this project is shown in Figure 1. The labor requirements for the same time period are shown in Figure 2. These schedules provided management with a firm basis for project monitoring and control.

3.2.2 Scope. The organizational schedules indicated above in Section 3.2.1, were extended and modified during the course of this project. In particular, delays in facility modifications and in the delivery of certain items of equipment caused an overall extension of about six months to the completion of this project.

In addition to the requirements of the contract specified in Section 3.1.2, equipment specifications, price schedules, delivery schedules, maintenance procedures were developed.

Work Schedule Description	MONTH											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Project Organization												
2. Phase I												
3. Time Table for Equipment Delivery												
4. Order of All Equipment												
5. Finalization of Plant Layout												
6. Plant Preparation												
7. Laser Optical Design												
8. Laser Sealing Development												
9. Equipment Installation												
10. Operational Verification of Equipment												
11. BCL Nuclear Project Consultation												
12. Phase II												
13. Plant Optimization												
14. System Operational Parameters												
15. System Controls and Limitations												
16. Preliminary Quality Control Procedures												
17. Source Production Per CLIN 001AA-002AK												
18. Definition of Manufacturing Tolerances												
19. Final Quality Control Procedures												
20. Liquid Scintillation Diffusion Testing												
21. Monthly Letter Report												
22. Draft, Final Technical Report												
23. Final Technical Report												
24. Draft, Instruction Manuals												
25. Final Instruction Manuals												
26. Draft, Production Plan												
27. Final Production Plan												
28. Preliminary Drawings												
29. Final Drawings												
30. Travel												

Figure 1. Time/Work Schedule

Work Schedule Description	MONTH											
	13	14	15	16	17	18	19	20	21	22	23	24
1. Project Organization												
2. Phase I												
3. Time Table for Equipment Delivery												
4. Order of All Equipment												
5. Finalization of Plant Layout												
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24. Draft, Instruction Manuals												
25. Final Instruction Manuals												
26. Draft, Production Plan												
27. Final Production Plan												
28. Preliminary Drawings												
29. Final Drawings												
30. Travel												

Figure 1. Time/Work Schedule (cont'd)

LABOR DESIGNATION	MONTH											
	1	2	3	4	5	6	7	8	9	10	11	12
Project Engineer	100	100	100	100	100	100	100	100	100	100	100	100
Senior Engineer	60	60	60	60	60	60	60	60	60	60	60	60
Nuclear Technician	40	40	40	40	40	40	40	40	40	40	40	40
Drafting Layout	10	10	10	10	10	10	40	40	40	40	40	40
Construction Coordinator	60	40	40									
Assembly Technician										20	100	100
Shop						10	10	10	10			
BCL Consultation									170	170		
Instruction Manual								50	50	50	50	100

Contract No. DAAK02-74-C-0147
American Atomics Corporation CWO #630

Starting Date: January 24, 1974
Completion Date: October 24, 1975

Figure 2. Original Labor Schedule

LABOR DESIGNATION	MONTH											
	13	14	15	16	17	18	19	20	21			
Project Engineer	100	100	100	10	10	10	10	10				
Senior Engineer	60	40										
Nuclear Technician	40	30										
Drafting Layout	10	10	10	10								
Construction Coordinator												
Assembly Technician	100	100	100									
Shop												
BCL Consultation												
Instruction Manual	100	100	100	100	100	100	50	50				

Contract No. DAAK02-74-C-0147
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Starting Date: January 24, 1974
Completion Date: October 24, 1975

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Figure 2. Original Labor Schedule (con't)

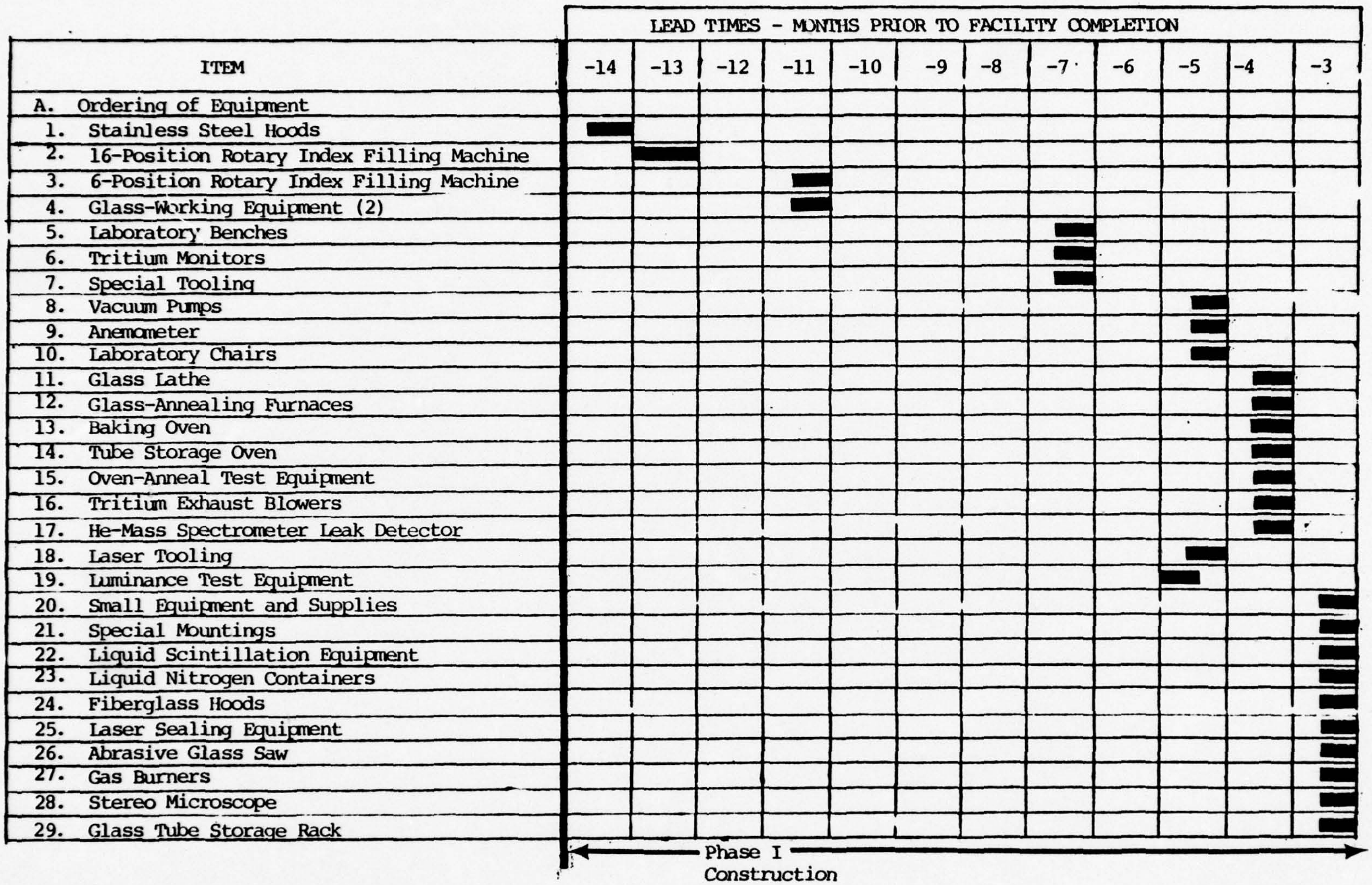

Figure 3. Time Phasing - Production Plan

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Figure 3. Time Phasing and Lead Times

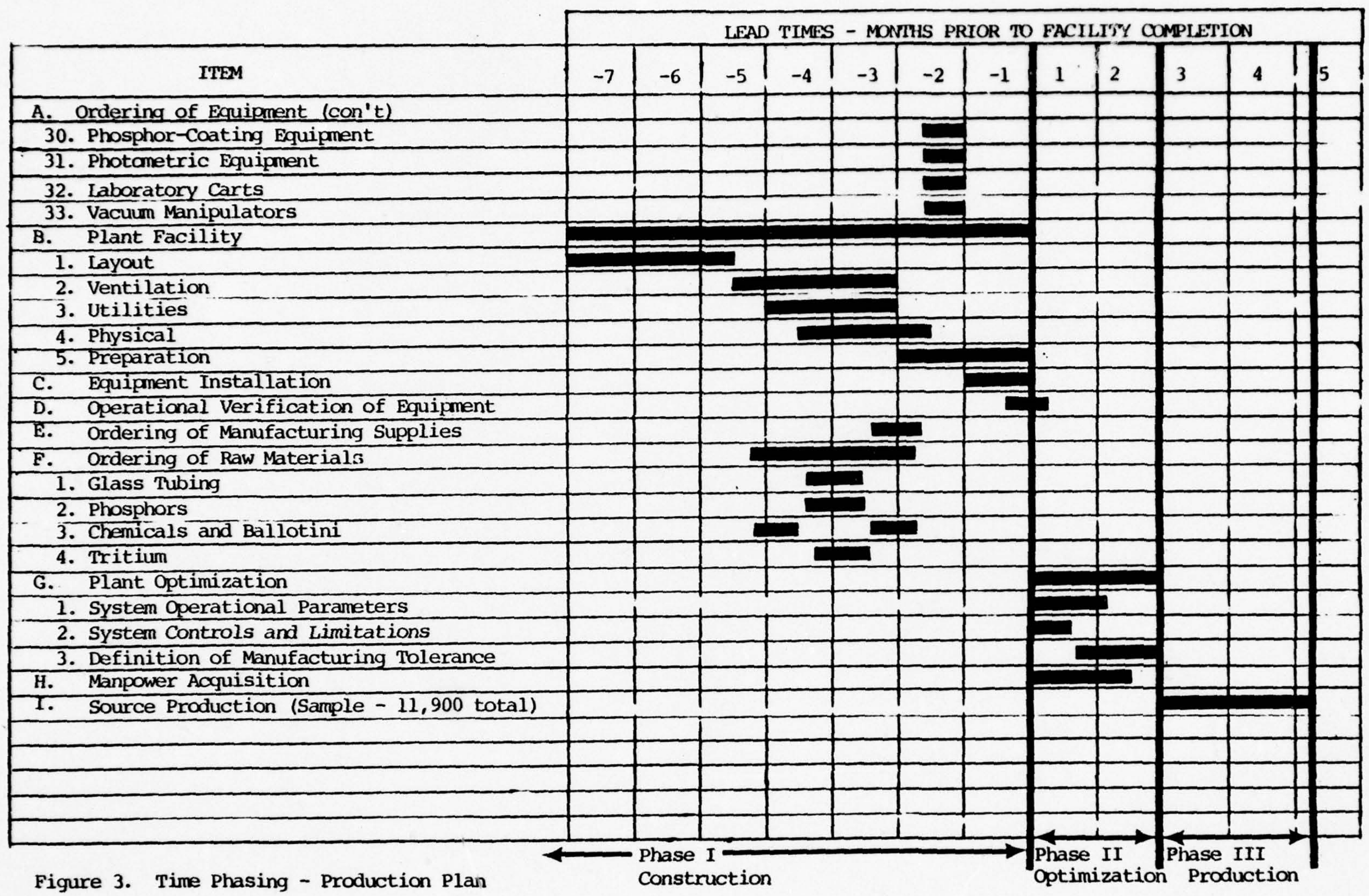

Figure 3. Time Phasing - Production Plan

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Figure 3. Time Phasing and Lead Times (con't)

4.0 PROJECT RESULTS

4.1 Phase I - plant construction.

4.1.1 Site preparation. Site preparation first required the selection of a suitable site for this type of facility. Adequate floor space and area are necessary for the proper integration of all manufacturing procedures. Area requirements had been specified previously in a general manner. (See Section 4.1.6 for specific floor space requirements for the various functional areas within the facility.) In addition, site selection involved proper consideration for the radiological hazards of this facility. A preliminary hazard analysis[1] for this type of facility was completed as part of the design effort, and included an evaluation of hazards associated with tritium gas for the purpose of analyzing a tritium handling facility which could contain up to 40,000 curies of tritium in inventory. Another critical factor was the availability of personnel trained in radioactive gas handling and procedures, and in the overlapping areas of vacuum systems, glassworking, luminance and scintillation testing, and hermetic seals.

Taking into account these factors, it was decided that this facility would be constructed on the grounds of American Atomics Corporation, Tucson, Arizona. The site was prepared and laid out in a manner which result-

[1] R. J. Doda, Safety Hazard and Hazard Evaluation Report for Automatic Production System for Radioluminous Sources, 472/AA-41-3, American Atomics Corporation, Tucson, Arizona, March 30, 1973.

ed in the greatest efficiency for overall manufacturing operations. This overall layout is shown in Fig. 19, Dwg. No. SK-1204 in Appendix A. The interconnection of the manufacturing areas will be discussed later. It should be noted that the liquid scintillation testing area was located in a separate, self-contained building in order to minimize cross-contamination and to maximize the sensitivity of the counting equipment. All plant modifications and utility requirements were completed with this layout as the basis for equipment location.

Facility preparation lead times are shown in Item B of Figure 3 Preparation of the facility included meeting not only the specification requirements of the equipment, but also the specification requirements of each manufacturing area. It can be seen that facility preparation required approximately seven months to complete. It must be noted that some equipment installation was being performed during this time. The area requirements are specified in Section 4.1.6 and the equipment requirements are in the equipment specifications given in Appendix B.

The special exhaust requirements are covered in Appendix C. These results show calculations to determine the sizing and placement of the exhaust systems for the facility. The exhaust requirements are quite severe and require the movement of large volumes of air in order to provide the dilution factors which are required to meet Nuclear Regulatory Commission tritium concentration levels external to the facility (See Appendix C). These calculations formed the basis for the design of the exhaust systems for this facility. Also, the results of the calculations were checked with Arizona Atomic En-

ergy Commission data on the same subject. Under the assumed conditions, the calculated ground concentration was under the maximum allowable. It is projected that actual ground concentrations will be less than this calculated value due to the conservative assumptions contained in these calculations.

The lead times shown in Figure 3 are actual lead times experienced in the construction of this facility. It can be seen that the site and facility preparation requires approximately seven months to complete. It should be noted that these lead times are dependent heavily on the facilities which were available at the onset of the contract and on the modifications which were required to conform to the specifications of the operating tritium source facility. Modifying other facilities, or alternatively, constructing new facilities, could produce lead times that range far from those presented here for facility preparation.

4.1.2 Equipment lead times. Equipment lead times, that is, the time period between order and delivery of equipment, are shown as Item A, Figure 3. These are actual lead times experienced in the construction of this facility. The items of equipment with long delivery times were the stainless steel hoods, the 16-position rotary index filling machine, the six-position rotary index filling machine, and the glass-working equipment. All other equipment had a delivery time of six months or less. The actual delivery time of the two rotary index filling machines (11 months, and 15 months) is approximately six months longer than originally estimated by the manufacturer. This

fact necessitated an extension of the completion date of Phase I of the contract.

In actual practice, the equipment was ordered on a schedule which allowed its delivery to be integrated with plant facility modifications, ordering of manufacturing supplies, ordering of raw materials, and installation of the equipment.

4.1.3 Equipment installation. From Figure 3, it can be seen that final installation occurs during the last month of Phase I, construction of the facility. It must be realized that this is an ideal case in which all equipment would be on hand and in which all plant facilities, such as physical areas, ventilation systems, and utilities were available. In the actual case, each item of equipment was installed as soon as both equipment and facilities were available. Due to the self-contained nature of most of this equipment, it was operational almost immediately upon installation.

An additional item of equipment was manufactured as a result of planning procedures for the handling of tritium and for the filling of pyrophoric uranium containers. See Item F-4 of Figure 3. Pyrophoric uranium containers are used as sources of tritium for the filling machines. A continuing description of this equipment follows in Section 4.1.5.

4.1.4 Operational verification of equipment. All equipment was operated and tested immediately upon installation. No extensive modifications or changes in design were required for any equipment. All equipment was considered satisfactory in operation and available for immediate use except as follows:

The 16-position rotary index filling machine required special efforts due to (1) vacuum leaks in several of the rubber connectors which connect the different positions on the rotary index valve, and (2) the leak detection switch for pump out of the filling leg volume was malfunctioning. The rubber connectors were replaced where needed to provide satisfactory vacuum operation. The leak detection switch was repaired and recalibrated to a desired trip-level value. These repair efforts took approximately two weeks.

The laser sealing fixtures required the installation of an X-Y position device, because very precise placement under the laser beam was necessary for proper sealing of sources. The incorporation of the X-Y positioner took approximately three weeks total time.

4.1.5 Raw material acquisition. The acquisition of raw materials had to coincide with the completion of Phase I, construction of the facility, in order to proceed in a timely manner with the optimization and limited production requirements of the contract. Therefore, from Figure 3 it is shown that the raw materials were ordered three to four months prior to completion of Phase I. Since Oak Ridge National Laboratory would provide the tritium gas only in unabsorbed form, it was decided that pyrophoric uranium containers would be filled with tritium at this facility. This necessitated the construction of a tritium handling/vacuum pumping system within the tritium storage hood. This auxiliary project, funded by American Atomics Corporation, resulted in a system which is capable of vacuum pumping, leak checking, and tritium filling of spent pyrophoric uranium containers. This system also provides a means of tritium inventory control.

Raw materials for production consist of glass tubing of both rectangular and circular cross-section and various sizes, phosphors of required particle size and emission spectrum, and binder and ballotini for the coating operation, as well as tritium gas which is contained in storage cylinders and in pyrophoric uranium containers, for use on the filling machines. Lead times actually experienced for the acquisition of these materials are shown in Table 1.

4.1.6 Facility layout and work flow sequence. The facility layout and work flow sequence are presented as graphical representations of the facility layout and work flow diagrams with work station identification. Layouts of the individual work areas are presented in Fig. 19, Dwg. No. SK-1204 in Appendix A, and this drawing shows the floor plan which was developed to manufacture radioluminous light sources. A legend indicates location of all major items of equipment and all major operations within the facility. The following operations are contained in separate rooms within the facility:

1. Glass working,
2. Phosphor coating,
3. Tritium filling, tritium handling, auxiliary sealing and oven anneal testing,
4. Visual and dimensional testing,
5. Liquid scintillation testing. The liquid scintillation testing area was located in a separate self-contained building in order to minimize cross-contamination and to maximize the sensitivity of the counting equipment.

The movement of parts between the different manufacturing areas is simplified due to the fact that all the parts are small in size. Fig. 22, Dwg. No. SK-1208, in Appendix A shows the general parts flow within this facility. It can be seen that the parts move through this facility in a smooth and defined way for all stages of manufacturing except for the liquid scintillation test area which has purposely been kept separate for reasons as previously indicated.

The following tabulation presents the total floor area requirements:

Function	Floor Area (sq. ft.)
Glass Working	280
Phosphor Coating	280
Tritium Filling	240
Aux. (Laser) Sealing	115
Oven Anneal Test & Tritium Storage	105
Shipping and Receiving and Storage	180
QA Operations and Testing	650
Break Room and Offices	500
Total Floor Area Required	2350

The manufacturing flow sequence is shown in Fig. 21, Dwg. No. SK-1207 in Appendix A. This drawing shows the various manufacturing steps for tritium source production in graphical form. All parts move through this sequence, even though some may require only sample testing. The packaging of bare tritium light sources is shown in Figure 4. It should be noted that this final step in the manufacturing sequence may require the packaging of various types of components containing mounted tritium tubes. In such cases, the packaging requirements are dictated by the size, weight, and type

of components in question.

4.1.7 Description of operations. There is essentially one manufacturing line that begins with the receipt of the glass tubing. Tritium gas, phosphors, and phosphor coating chemicals are the other materials used in manufacture. Equipment, input materials, production rates, and operational work sequences are defined.

The manufacturing process is represented pictorially in Fig.21, Dwg.No. SK-1207 , in Appendix A. After receiving materials, the manufacturing sequence is:

1. Glass cutting. Glass tubing is cut into the proper lengths for the type of sources specified for manufacture.

2. Glass forming. The lengths of glass tubing are shaped and formed in molds, lathes, or glass machines. The parts are annealed in a glass annealing furnace according to the requirements of the type of glass tubing used.

3. Phosphor coating. A uniform phosphor coating is applied to the inside surfaces of these glass parts and the parts are baked and stored in Steps 4 (baking), and 5 (storage).

6. Tritium filling. The parts are vacuum pumped, leak checked, back-filled with tritium gas and sealed-off during the tritium filling operation.

7. Auxiliary glass sealing. Parts requiring auxiliary sealing pass this station before being sent to Step 8 (oven anneal test).

8. Oven anneal test. All tritium-filled tubes are oven-anneal tested.

9. Visual and dimensional testing. Visual and dimensional testing is performed on all sources.

10. Luminance testing. Luminance testing is performed on the sample required.

11. Liquid scintillation testing. Liquid scintillation testing is performed on the sample of tubes required.

12. Storage. Tubes are then stored until they are ready for packaging and shipping in Step 13 (package and ship).

Fig.17 , Dwg.No. SK-1138 In Appendix A shows the manufacturing block flow diagram. The six different types of sources are shown as Item 3 in this drawing. Sources are filled on either the 16-head or the six-head filling machine. Auxiliary glass sealing may or may not be required in the processing scheme.

Fig.19, Dwg.No. SK-1204 in Appendix A shows the equipment location in the tritium facility and Fig. 22 , Dwg. No. SK-1208 shows the general parts flow within this facility. The parts flow is, in order, as follows: glass working area, annealing area, phosphor coating area, tritium filling area, dimensional test area, luminance

test area, liquid scintillation test area and packaging and shipping area. Summary descriptions follow:

4.1.7.1 Glass shaping: After inspection, the tubing is cut into lengths that can be readily used on the glass shaping machine. Here, the glass tube is shaped into the configuration required. Results presented in Section 4.2 show that only one machine is required to meet the production level of 300 sources per hour. After shaping, the glass parts are placed in an oven for annealing. The annealing procedure is described in Section 4.2.1.1.

4.1.7.2 Phosphor coating: After annealing, the glass parts are phosphor coated. First, the glass parts are exposed internally to a ballotini/binder mixture by vibrating the source as the mixture is introduced inside the glass part. The excess is recovered. Phosphor is introduced into the glass part and it is again vibrated until a uniform coating is deposited. Excess phosphor is recovered and the glass parts are baked to "fix" the phosphor coating. Parts ready for tritium filling are stored in an oven. Results in Section 4.2 show that three to six coating stations are required, for the various types of parts.

4.1.7.3 Tritium filling: A 16-head rotary index filling system is used to fill non-pressurized sources. The phosphor coated glass parts are loaded into the machine which automatically indexes them through the 16-positions where the glass parts are leak checked, evacuated, filled with tritium gas, and sealed off by the operator. Pressurized sources are run through the same sequence on the six-head rotary

index filling system. After the sources are filled and sealed, small sources are moved to the auxiliary sealing stations, if required.

4.1.7.4 Auxiliary sealing: A length of phosphor-coated and tritium-filled tube is placed in the auxiliary sealing fixture, and a laser beam is used to cut the tubes to the proper length and seal them in one operation. At another station, sources may be sealed by torch, if required by the particular source type which is being sealed.

4.1.7.5 Oven anneal testing: After the sources are sealed, they must be annealed to remove strains from the glass. Oven anneal testing is a batch operation where a single day's production is loaded into an oven and run through a temperature cycle that anneals the glass and the phosphor. Sources with improper seals will rupture and lose luminosity, making them easy to separate, during the visual test. This rather severe test has a two-fold purpose. The first is to remove the darkened area on the phosphor coating, nearest to where the seal was made, by temperature annealing. The second is to subject the sealed tip to a higher temperature stress than the part would ever receive in use. Fragile or improper seals will not survive this test.

4.1.7.6 Testing: After annealing, the sources are checked for visual and dimensional characteristics, luminance levels and sample-checked for leakage, by liquid scintillation techniques. Visual testing is performed on all manufactured parts. The other testing procedures may be performed on a sample basis or may be performed on all of the sources depending on the type and configuration of the sources being manufactured.

4.1.7.7 Quality control: Process quality control procedures are contained in the Quality Control Manual for Tritium Operations[1]. These procedures are intended to assure that tritium-filled self-luminous sources manufactured by this facility exhibit an outgoing quality level which is required by given specifications. Also, these procedures are designed to provide for early detection of discrepancies and for positive correction of these discrepancies. The inspection sequence, which is shown in Fig. 20, Dwg.No. SK-1205 and graphically displayed in Figure 18, Appendix A is as follows:

1. Receiving log - materials logged in as received.

2. Receiving inspection - this inspection is performed after materials are received.

3. Glass forming inspection - this inspection is performed after glass parts are formed.

4. Phosphor-coating inspection - this inspection is performed after parts are phosphor-coated.

5. Visual/dimensional inspection- this inspection is performed after visual and dimensional testing is completed.

6. Luminance inspection - This inspection is performed after luminance testing is completed.

[1]Quality Control Manual, Tritium Operations, American Atomics Corporation Specification No. 9014, American Atomics Corporation, Tucson, Arizona, January 31,1975

7. Liquid scintillation inspection - this inspections is performed after liquid scintillation testing is completed.

8. Shipping inspection - this inspection is performed after parts are packaged and ready for shipment.

It is the responsibility of Quality Control personnel to perform all inspections and to assure that all inspection records are complete. All details are contained in the Quality Control Manual for Tritium Operations[1].

4.1.7.8 Storage: Bare tritium-filled tubes are stored in an exhaust hood until they are processed for shipment. Mounted tritium-filled tubes, usually, are stored in a remote, monitored area until they are processed for shipment.

4.1.7.9 Packaging and shipping: Source packaging requirements are determined on an individual basis. Quantity, size, shape and activity are the determining characteristics. Sources may be mounted on components and thus packaging requirements will be determined largely by these components themselves. Normally, bare sources are packaged in sealed cans for safety and containment. The tubes are protected from shock, and leaking tritium is contained within the cans, until opened in exhaust hoods or other suitable areas. See Figure 4. Also see Section 4.1.9.

[1] Quality Control Manual, Tritium Operations, American Atomics Corporation Specification No. 9014, American Atomics Corporation, Tucson, Arizona, January 31, 1975

4.1.8 Material handling.

4.1.8.1 Procedures. Since the materials involved in the manufacture of tritium light sources are all small in size and weight, there are no large material handling requirements. No separate personnel are required for material handling, as each section requiring movement of materials uses its own personnel.

Glass working requires the movement of glass tubing and parts. This is done by the operator requiring the material. Glass tubing is received in boxes with bundles of glass tubing weighing in increments of ten pounds, which can easily be carried to the glass working section. Parts are moved in trays on stainless steel lab carts.

Phosphor-coating requires the movement of phosphor, ballotini, binder and solvents. These are contained in five-pound shelf jars for containers, which are easily handled by the operators with no special equipment required. Parts are moved in beakers or trays on stainless steel lab carts.

Tritium-filling requires the movement of the tritium cylinders and glass parts. The cylinders are moved using carts or hand trucks. The connection of the pyrophoric uranium tritium containers is done by the operators and requires no special handling. Tritium storage is in the same room as the filling operation. Finished sources are moved in beakers on stainless steel lab carts.

Auxiliary sealing and oven anneal testing involves the movement of parts which are moved in beakers on stainless steel lab carts. Auxiliary sealing also involves the movement of gas cylinders which is performed with a hand truck by the operator.

The general parts flow and direction of movement is shown in Fig.22, Dwg.No. SK-1208 in Appendix A. It is readily apparent that material handling presents no problem with the movement of lab carts through all areas of the facility.

It should be noted that the liquid scintillation test area has been chosen purposely as a self-contained structure which is remote from the other operations of the facility. This provides for the most limited contamination from tritium from other areas and, thus, produces the maximum sensitivity for this test equipment.

Other source or small part handling (i.e., handling within exhaust hoods) is performed with the use of small tweezers or vacuum manipulators.

4.1.8.2 Equipment. Equipment listing for material handling is as follows:

1. Stainless steel lab carts.
2. Closed jars.
3. Fiberglass trays.
4. Glass beakers.
5. Tritium cylinders.
6. Tweezers.
7. Vacuum manipulators.

4.1.9 Packaging and shipping. Packaging and shipping of tritium radioluminous sources are divided into two separate categories: (1) packaging and shipping of bare tritium sources, and (2) packaging and shipping of components that contain mounted tritium sources. Procedures for the handling of components that contain mounted sources are specific in nature and are highly dependent on the type of component being used. As such, they will not be discussed further here, except to indicate that in most cases the packaging requirements for components are simple and straightforward. Shipping requirements would be similar to any other tritium source shipments.

4.1.9.1 Procedures. Packaging of bare tritium sources is as shown in Figure 4 . The sources are enclosed in sealed plastic bags, with activity level and size of source determining the quantity in each bag. These bags are placed within cushioning material inside a standard sealable can. The cans are sealed and labeled before being boxed for shipment. Radioactive shipment requirements must be adhered to with respect to labeling and boxing.

4.1.9.2 Materials. Packaging and shipping materials are as follcws:

1. Plastic poly bags (.0015 to .002 inches thickness).

2. Cushioning material - expanded polyethylene or Kimpak paper.

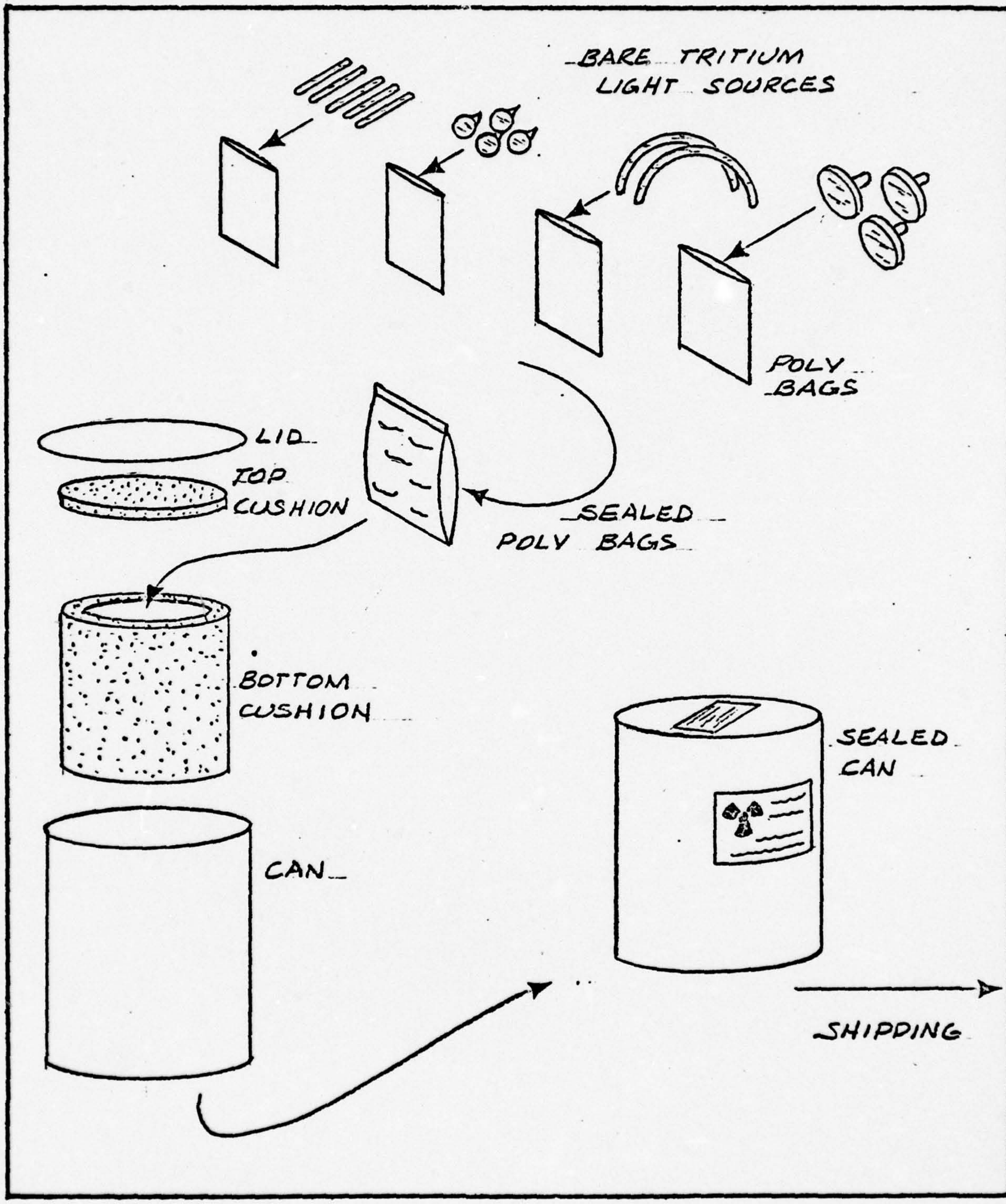

Figure 4. Packaging of Bare Tritium Sources

3. No. 603 x 700 cans with lids.

4. Labels.

5. Corrogated boxes.

4.1.9.3 Equipment. Packaging and shipping equipment is as follows:

1. Can sealing machine.

2. Poly bag heat sealer.

3. Box stapling machine.

4.2 Phase II, facility optimization and limited production. As shown in Figure 3, Time Phasing Optimization, and Limited Production are separate and distinct. However, in the actual fulfillment of the requirements of this project, these two phases were over-lapping and in fact required concurrent operation due to the type of sources specified for manufacture. Plant optimization, which determines system operational parameters, defines restrictions on system controls and defines feasible manufacturing tolerances required approximately two months to complete. The limited production, that is 11,900 sources, also required approximately two months to complete.

4.2.1 Optimization of operations. Optimization operations began as soon as Phase I - construction was completed and accepted. All equipment was operationally verified and all of the facility's systems and utilities were complete and operational before optimization procedures began. This section presents a description of the manufacturing operations which were determined during optimization. Equipment, input materials, production rates and operational work sequences are defined. Fig.17, Dwg. No.SK-1138 in Appendix A shows the processing system in block form.

4.2.1.1 Glass shaping optimization. The glass shaping section forms the various geometrical shapes and sizes. Six basic geometrical shapes are available from the glass shaping section. These are:

a. Cylindrical
b. Rectangular
c. Spherical
d. Button
e. Curved Cylindrical

f. Curved Rectangular

4.2.1.1.1 Process description. The production of cylindrical sources is accomplished on the tube constricting machine. The outside diameters vary from 1 mm to 7 mm, with lengths from 15 mm to 150 mm. The sequence of operations is shown in Fig. 33, Dwg. No. P1167 in Appendix A. The number of sources that can be produced per hour is 720.

The production of rectangular sources is as follows: A unit of rectangular glass tubing open at both ends is placed in the work holder shown in Figure 28, Appendix A. This work holder is fitted with an appropriate template. A mini-torch gas flame is directed onto the glass tube at each of the template openings, thus imposing a series of dimples along one side of the tube length. The work holder is rotated through 180 degrees, and the dimpling process is repeated. The dimpled tube is removed from the work holder, and one end is sealed off. This tube is then loaded into the chuck of a standard glass-working lathe, and a 1.5 inch length of circular tubing (normally 3 mm diameter) is fitted into the opposing chuck. The two tubes are brought into contact and joined using an appropriate size flame. The internal bore of the joint is formed to the appropriate size by low pressure air introduced at the open end. This process sequence is depicted in Figure 25, Appendix A. This multiple-source unit is then ready for the glass annealing step. Production rate is 35 per hour (350 individual units per hour).

The production of spherical sources is accomplished on the glassworking machine. Production range of manu-

factured components is 5mm to 11mm outside diameter. The sequence of operations is shown in Fig. 31 in Appendix A. Production rate is 360 per hour.

The production of button sources is accomplished on the glass-working machine. This machine is capable of producing disc sources in the range of 5mm to 10mm outside diameter with a thickness of 3mm (excluding the filling tip). The sequence of operations is shown in Fig. 32 in Appendix A. Production rate is 360 per hour.

The production of curved cylindrical sources is accomplished by the following method: First, glass tubing of correct diameter is cut to suitable lengths. Fig. 29 in Appendix A shows in detail the bench layout and shows the components used in the forming operation. Fig. 29 in Appendix A illustrates the following sequence of operations.

1. Unit length of glass tubing is heated in the ribbon burner flame to a softened state.

2. The softened glass tube is wrapped around the former to the shape as shown in stage one, Fig. 30, and then released by operating the knee lever.

3. The part is then passed to a second operator who then separates the curved-glass tube as shown in stage two, Fig. 30.

4. The part is handed to a third operator who constricts the glass tubing at a point determined by the requirements of the finished component specification.

The production rate of curved cylindrical tubes is 360 per hour.

The production of curved rectangular sources is similar to that of curved cylindrical sources as explained above when the curve is around the thin cross-section. Curving the rectangular tubing around the thick cross-section is more difficult and is recommended only for sources with a large radius and a small arc. A specific mold is required for each size part.

All shaped glass parts must be thermally annealed to remove residual strains in the glass. The glass parts are loaded into beakers and put into the oven where they are run through the annealing cycle. The parts are brought up to a temperature of 550°C and held for 15 minutes. They are then cooled at a rate not exceeding 10°C per minute. This is a batch operation and can be done at the end of a day's production and allows the cooling cycle to take place at night.

4.2.1.1.2 Process operations.

1. Receive glass tubing.
2. Receiving inspection.
3. Store tubing.
4. Transfer to glassworking area.
5. Cut tubing to working lengths.

6. Insert glass into glassworking machinery.
7. Shape glass to proper configuration.
8. Store glass parts for annealing
9. Insert glass parts into annealing oven.

10. Heat parts to 550°C for 15 minutes.
11. Allow to cool - rate not to exceed 10°C per minute.

4.2.1.1.3 Outline specification equipment and tools. The glassworking equipment is composed of six major items of equipment as follows: (Also, see equipment specifications in Appendix B.)

1. Glassworking machine.
2. Glassworking lathe.
3. Glass cutting saw.
4. Miscellaneous glassworking equipment.
5. Annealing ovens.
6. Tube constricting machine.

Glassworking machine:

The glassworking machine is a Model MB 14 Pay Lamp Machinery Machine. This is a nine-head glass-forming machine with automatic indexing.

Glassworking lathe:

The glassworking lathe is a standard small lathe made by Bethlehem Apparatus Company, Inc., Model No. GL-25A.

Glass cutting saw:

The glass cutting saw is a Model No. 11-B by

Felker Manufacturing. It is a small wet cut-off saw used in cutting lengths of tubing.

Glassworking equipment:

The shaping of the glass sources requires some small equipment such as a scoring knife, didymium spectacles, tweezers, graphite shaping tools, gas burners, asbestos tape, molds, and fixtures.

Annealing Oven:

The annealing ovens are ovens capable of reaching temperatures of 550°C, and cooling slowly over the annealing range. The oven is a Gruenberg Model No. B120C16 oven.

Tube constricting machine:

The tube constricting machine is a Pay Lamp Machinery Model No. FD Machine. It is a four burner type with automatic indexing.

4.2.1.1.4 Results. The manufacturing capabilities were developed for all source shapes.

4.2.1.1.4.1 The production of the straight rectangular sources at a rate of 300/hr. requires three technicians and 2 glass lathes. Training of glassworking technicians is dependent, to a large extent, upon their dexterity and aptitude. If the technicians are suitable the training period required for the attachment of circular to rectangular cross-section tubing is approximately 1 week. During the training period approximately 10 meters of rectangular cross-section glass will be used.

4.2.1.1.4.2 Curved rectangular production closely parallels straight rectangular in the first 3 stages. The added complication of this production is the bending the tubing around the thick cross-section. The bending requires a training period of approximately 3 days, and the use of 20-30 meters of glass. Until a technician has had approximately 1 month experience bending, a production rate of 300/hr. requires 4 technicians and 2 glass lathes.

4.2.1.1.4.3 Production of lengths of 2mm square cross-section requires the experience developed manufacturing the rectangular cross-section tubes. The operation consists of attaching a 2mm fill tube to a length of 2mm x 2mm tubing. For a production rate of 300/hr., 2 technicians and 2 glass lathes are required.

4.2.1.1.4.4 The production of 20mm x 20mm x 3mm flat sources is a very labor intensive operation. This manufacturing is accomplished completely by hand. The glass is purchased in 3mm x 20mm cross-section. The glass is cut to length, a fill tube attached and the end sealed.

The training period required is dependent upon the technicians' capability. Only the best technician can be trained to accomplish this job. Something on the order of tw weeks training and the use of approximately 10 meters of glass should be expected. This type of production does not lend itself to large quantity production; if multiple thousand orders were anticipated another production method would have to be pursued.

4.2.1.1.4.5 Disc production with 20mm diameter and 3mm thickness also requires a very skilled technician. In this case the glass lathe is used to form a disc from 20mm OD glass tubing and attach a fill tube. What has been stated above about training and production also applies to the production of the disc source.

4.2.1.2 Phosphor coating optimization. The phosphor coating system is designed to uniformly deposit a thin layer of phosphor crystals on the inside wall of glass light source units of variable size and configuration. The uniformity of the phosphor coating is of primary importance as it determines the quality of the source and the quantity of light from the source. The phosphor layer should be thin enough to pass the light generated within, yet thick enough to absorb a large portion of the beta energy generated by the tritium gas.

4.2.1.2.1 Process description. The uniform coating on the inside of glass light source units, some of very small inside diameter, with phosphor crystals is accomplished in three main operations: (1) binder spreading, (2) phosphor deposition, and (3) baking. The binder spreading composition is prepared from ballotini and binder solution. The ballotini is first cleaned and degreased by forming a slurry with an aqueous cleaning solution. After mixing thoroughly and letting stand for two to three hours, the slurry is poured onto a sintered glass filter, washed with water, then acetone, and finally dried at 150°C to 200°C. The ballotini/binder composition is prepared by adding 30 milliliters of binder solution to 1000 grams of ballotini contained in a 1000 milliliter polyethylene bottle. The composition is shaken at frequent intervals over a seven to ten day period and then it is ready for use. The binder spreading composition is vibrated from a supply dispenser into a light source unit so as to occupy approximately 1/3 of the volume. Fig. 26 in Appendix A shows the motor mount and a 1/2 inch across/flats hexagonal aluminum rod.

The binder composition is vibrated over the internal surface of the source, and then the excess is emptied out leaving a thin coating of phosphoric acid binder.

A small amount of phosphor is introduced into the light source unit and vibrated over the surface in the same manner. The excess is removed leaving behind a thin uniform coating of phosphor. The excess phosphor is not reused.

Fig. 27 in Appendix A shows this process. Stage one shows the filling of the light source unit with ballotini/binder or phosphor. Stage two shows the vibration of the light source unit over its length. Stage three shows the inversion of the light source unit and removal of the ballotini/binder or phosphor.

The phosphor light source units must be baked after phosphor coating, to fix the phosphor layer, by heating over the temperature range 20°C to 400°C to 50°C over a period of five hours. The 400°C temperature is maintained for one hour. After this baking process, the light source units are stored at a temperature of approximately 100°C. to 150°C until required for use at the next stage of the manufacturing process. This heated storage facility has the capacity for two days storage.

Table 1. Production Lead Time for Materials

Number	Item	Lead Time (Month)
1.	Tritium Gas	1
2.	Phosphors, Standard	1
3.	Phosphors, Special	6
4.	Ballotini	1
5.	Chemicals (Phosphor Coating)	1
6.	Glass Tubing (Standard Circular)	1
7.	Glass Tubing (Special Circular)	2
8.	Glass Tubing (Standard Rectangular)	2
9.	Glass Tubing (Special Rectangular)	2

4.2.1.2.2 Process operations.

1. Wash and dry ballotini.
2. Mix ballotini/binder composition.
3. Remove glass light source units from annealing oven.
4. Inspection.
5. Vibrate ballotini/binder mixture over surface of glass light source units.
6. Remove excess ballotini/binder mixture.
7. Vibrate phosphor over surface of glass light source units.
8. Remove excess phosphor.
9. Bake glass light source units to fix phosphor.
10. Store the coated light source units.

4.2.1.2.3 Outline specification equipment and tools. The phosphor coating system is composed of four major types of equipment as follows: (Also, see equipment specifications in Appendix B.)

1. Laboratory equipment, beakers, balances, filters, stirrers, ring stands and benches.
2. Storage oven.
3. Vibrating stations.
4. Baking oven.

Laboratory equipment:

The laboratory equipment consists of stirring machines for the mixing operations, assorted beakers for containing the compositions and the glass light source units, balances for weighing out the compositions, filters for the cleaning of the ballotini, ring stands for

the vibrating stations, and benches for mounting the equipment.

Vibrating equipment:

Each of the vibrating stations shown in Figure 26 in Appendix A, consists of a small motor, mount, hexagonal rod and speed control.

Baking Oven:

The baking oven is an oven capable of reaching 400°C, and the one used presently is the Gruenberg Model No. B120C16 oven.

Storage Oven:

The storage oven is an oven capable of holding two day's production or approximately 5000 parts of various sizes and shapes. Temperature should range to 200°C. This oven is a Gruenberg Model EC015.

4.2.1.2.4 Results. The phosphor coating quality is very dependent upon the experience of the technicians. The training period of the technicians is dependent to a great extent upon their capabilities and patience. A two week training period should be expected as a minimum. The different sources require different techniques to achieve uniform coating. An initial reject rate of 15% is not unusual as quality is dependent upon experience. The 1mm tubing was found to be the most difficult to coat. Some glass breakage does occur in the coating area especially during the training period and with very fragile parts: 10-20%. The production rate of this section is completely dependent upon the number of technicians used. Three technicians should be able to coat tubes from glassworking at the stated production levels.

4.2.1.3 Tritium filling optimization. The tritium filling system is designed to fill glass light source units with tritium and seal them. Specially developed items of equipment handle the whole sequence of operations involving:

1. Leak detection of glass light source units.
2. Vacuum pumping.
3. Backfilling with tritium gas.
4. Seal-off of glass light source units.
5. Recovery of tritium gas.

Two pieces of equipment are used for tritium filling. A 16-head rotary index filling unit is used for the filling of non-pressurized sources, while a six-head inverted rotary index filling unit is used for the filling of pressurized sources, and for the filling of prototype units.

4.2.1.3.1 Process description. The filling of tritium light source units involves a minimum of operator responsibilities due to the design of the equipment. The glass light source units are removed from the storage oven and taken to the filling units. The index cycle time of the 16-position machine is ten seconds. This produces 360 source units per hour and provides a confortable operator time period to load and remove sources. The index cycle time of the six-position inverted head machine is two minutes. This produces 30 sources per hour. In the 16-position machine operation, the operator inserts the glass light source unit into the loading port, and the unit is sequenced through the operations shown in Fig.23..

in Appendix A. If the loading port is designated as Port 1, then in a counter clockwise operation, the function of each port is as follows:

Port 1. Load source. Compression fitting is automatically tightened and does not require operator action.

Port 2. Leak detection. Detects a leak in the port either due to a faulty source or the lack of a source. Unless the source is intact, the port is sealed off for all subsequent operations.

Port 3
through
12. Vacuum pumping. Ports 3, 4 and 5 are connected to a single-stage rotary pump; Ports 6, 7 and 8 to another single-stage rotary pump; Ports 9, 10, 11 and 12 are connected to a diffusion pump with cold trap utilizing a single-stage rotary pump for the foreline.

Port 13. Back filling with tritium gas & seal-off of source. Tritium gas with a pre-determined pressure is introduced into the source at this port. The operator is required to use a spring loaded torch assembly to seal off the source. After seal-off, the torch assembly moves back to its ready position.

Leak detection of the seal-off tip. This is required to determine if tritium recovery should occur. If the seal-off tip is tight, tritium recovery is performed at the next two ports.

Port 14. Primary tritium recovery.

Port 15. Secondary tritium recovery.

Port 16. Vacuum out leg and seal off tip.

Port 1. Operator removes tip and loads new source unit.

The operator is not required to open or close any valves, or perform other normally essential functions.

The compression fittings are used for all source connections. A 3mm filling tube is a convenient size to use for most sources. For other size fill tubes, other small interchangeable inserts can be used in these fittings. 1mm and 2mm compression fittings have been produced for this machine. All fill tubes must be round, thus any size round fill tube may be used for any source, and also must be used with rectangular sources.

The method of supply and recovery of tritium uses pyrophoric uranium containers. These containers are basically a stainless steel housing with a vacuum valve inclosing activated uranium turnings. Tritium is absorbed through hydride formation. Tritium is supplied to the filling units by heating these containers to a temperature of about 400°C to 500°C until the desired pressure of tritium is reached. When this unit is cooled to room temperature it acts as a sink, thus recovering the tritium. In operation, three of these containers are used, one as a supply, one for primary recovery, one for secondary recovery.

The operation of the six-position inverted filling machine is similar to the 16-position machine with the addition of the capacity to cryogenically cool glass light source units in order to fill pressurized sources. The operator inserts the glass light source unit

into the loading port, and the unit is sequenced through the operations by a manually operated index switch (as shown in Figure 24, Appendix A). The function of the six different ports is as follows: Starting at Port 1 -

Port 1. Load source in compression fitting and leak detection.

Port 2. Vacuum pumping.

Port 3. Vacuum pumping.

Port 4. Vacuum pumping.

Port 5. Back filling with tritium gas. Tritium gas of a predetermined pressure is introduced into the source at this port. Also, seal-off of source occurs, after cooling to cryogenic temperatures. The operator is required to flame seal-off the source with a small torch assembly.

Port 6. Tritium recovery.

Filling pressurized sources requires the source to be cryogenically cooled prior to the seal-off operation. After seal-off and warming, the internal pressure of tritium will be about 2-1/2 atmospheres.

The six-position machine uses the identical tritium containers as the 16-position machine ~~uses~~.

4.2.1.3.2 Process operations

1. Receive tritium containers.
2. Inspect containers.
3. Store containers.
4. Load tritium pyrophoric units.
5. Load glass light source units.
6. Index machine through operations.
7. Seal-off source using torch assembly.
8. Remove tip.
9. Store radioluminous source units for auxiliary sealing or oven anneal testing.

4.2.1.3.3 Outline specification equipment and tools. The tritium filling system is composed of two main items of equipments as follows: (Also, see equipment specifications in Appendix B.)

1. 16-position rotary index filling machine.
2. Six-position rotary index filling machine.

1. 16-position rotary index filling machine:

The 16-position rotary index filling machine is used to fill the glass light source units. The filling machine has a rotating table with 16 ports. The function of these ports is described in Section 4.2.1.3.1, process description. The vacuum pumping utilizes three rotary vacuum pumps and one diffusion pump. The tritium is supplied from a stainless steel container which has the tritium contained as uranium tritide Heating this container releases the tritium. The torch assembly is a mini torch utilizing natural gas and oxygen to seal-off the glass light source units. This specially desigend piece of equipment is manufactured by Brandhurst Company, Ltd.

Cressex Industrial Estate, High Wycombe, Bucks, England.

2. 6-position inverted rotary index filling machine:

The 6-position inverted rotary index filling machine is used to fill pressurized glass light sources and prototype units. The machine has a rotating table with six ports and can be manually indexed. The function of each of these six positions is described in Section 4.2.1.3.1. The same method is used for supplying and recovering the tritium as is used with the 16-position machine. This specially designed piece of equipment is manufactured by Brandhurst Company, Limited, Cressex Industrial Estate, High Wycombe, Bucks, England.

4.2.1.3.4 Filling was accomplished in the following manner:

6 pos. rig.
St. Rect. 0002AC
Curved Rect. 0002AD
20x20x3 flats 0002AE-0002AG
20mm disc. 0002AH, 0002AI

16 pos. rig.
2mm 0002AA
1mm 0002AB
2x2mm 0002AJ

Primarily it was determined that the production of the quantity required was not sufficient to completely optimize the filling operation. Personnel were trained on rigs using hydrogen and were just beginning to develop out their learning curves when the production quantity was achieved. A quantity of coated parts equal to or greater than the required production quantity was used for training purposes. Using the 6 pos. machine a production rate of 500 rectangular and 300 curved rectangular tubes/day was achieved. Knowing this it is projected that approximately 3-6 mo. of steady production would be required to optimize and establish the operating parameters of the filling operation.

4.2.1.4.1 The optimization phase has shown that the system can achieve a production rate of 300/hr. if it modified into the vertical position with the utilization of close tolerance mounting and fixturing. The system as it exists is a prototype very useful for $ & D but not production oriented.

4.2.1.4 Auxiliary sealing optimization. Auxiliary source sealing may be accomplished by one of two methods - either torch sealing by hand, or laser sealing by use of the laser sealing fixture.

The auxiliary laser sealing system is used to cut off and seal small glass light sources. A specially designed piece of equipment is used to hold and move tritium filled glass light source units so that a CO_2 laser can cut and seal parts to the desired length. This system is used mainly on small parts which are difficult to seal using a torch. The main pieces of equipment are the glass light source unit moving device and the laser.

Torch sealing by hand is accomplished by the use of a miniature natural gas torch and is required in the production of odd-shaped source configurations.

4.2.1.4.1 Process description. The laser sealing of tritium light source units involves taking the light source units from the tritium filling system, and using a laser, cutting and sealing individual light sources. The light source units are placed in a device which locates them and moves the units through the laser beam in such a manner so as to give very even, uniform seal-offs, much superior to small flame sealed sources. The operator places the light source unit in the moving device. The laser is operated manually so as to remove any danger to the operator. The light source is removed and the glass light source unit is moved to allow the cut-off of another light source.

Torch sealing by hand involves moving the light source units in front of a small miniature gas torch flame and removing the individual light sources, with a pair of tweezers, while being sealed.

4.2.1.4.2 Process operations. (Laser sealing)

1. Place glass light source unit in the fixture.
2. Activate fixture movement.
3. Activate laser.
4. Remove glass light source.
5. Move glass light source unit to cut off another light source.

4.2.1.4.3 Outline specification equipment and tools. The auxiliary laser sealing system is composed of three main pieces of equipment: (Also, see equipment specifications in Appendix B.)

1. Stainless steel laboratory hood.
2. Glass light source movement fixture.
3. CO_2 laser and accessories.

Stainless steel hood:

The stainless steel hood is an Argonne type hood that is 60 inches long x 24 inches wide x 40 inches high. This hood is without a blower, but the blower, plenum and stack design are based on calculations shown in Appendix D. The front face is clear glass or acrylic, and the sliding sash can accommodate glove ports if necessary. One side is

modified to accept the laser head.

Glass light source movement fixture:

The fixture for laser sealing is manufactured by American Atomics Corporation. The fixture holds the tubular glass source length in such a way that both sides of the seal are supported. Then the laser beam is moved in such a way as to cause the tube to be sealed and separated.

CO_2 laser:

The laser used is a 50 watt continuous CO_2 laser available from Coherent Radiation, 3210 Porter Drive, Palo Alto, California. It is a Model 42 with a Model 473 Beam Bender, and water cooled/lens mount.

4.2.1.4.4 Results. Preliminary optimization results for laser sealing are shown in Figs. 5 through 11 An operating range is shown and, where possible, an optimum or preferred operating line is indicated. It is pointed out that an actual operating point must be defined by the overall adjustment of all of the parameters of sealing: (1) focused beam diameter, (2) laser power, (3) rotation speed, (4) internal pressure, (5) cooling time, (6) minimum length, (7) residual length, and (8) close tolerance control of fixturing equipment with regard to movement. The time of seal (timer setting) for all optimization results was in the range of 2-8 seconds.

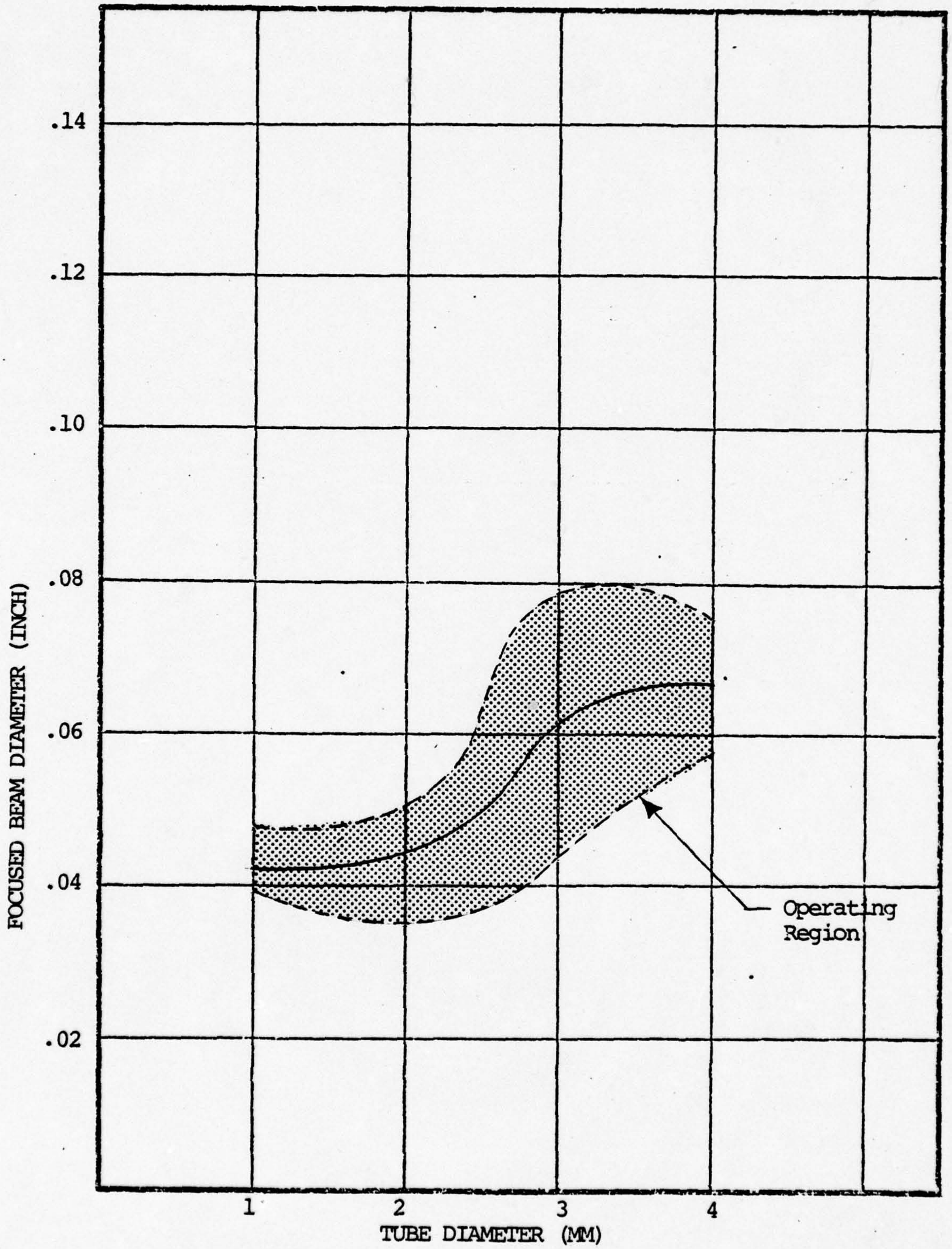

Figure 5. Tube Rotating Device, Focused Beam Diameter Relationship

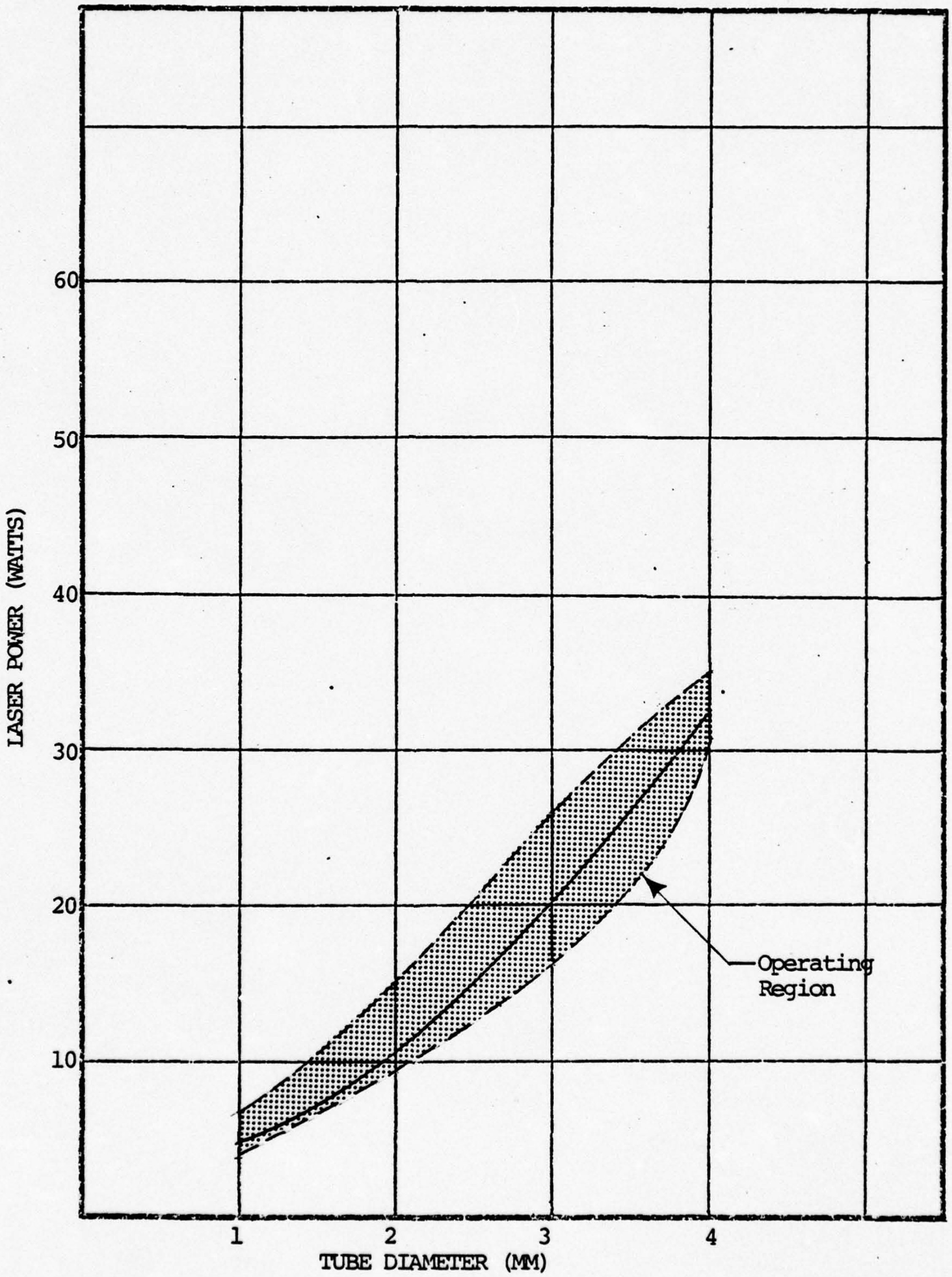

Figure 6. Tube Rotating Device, Laser Power Relationship

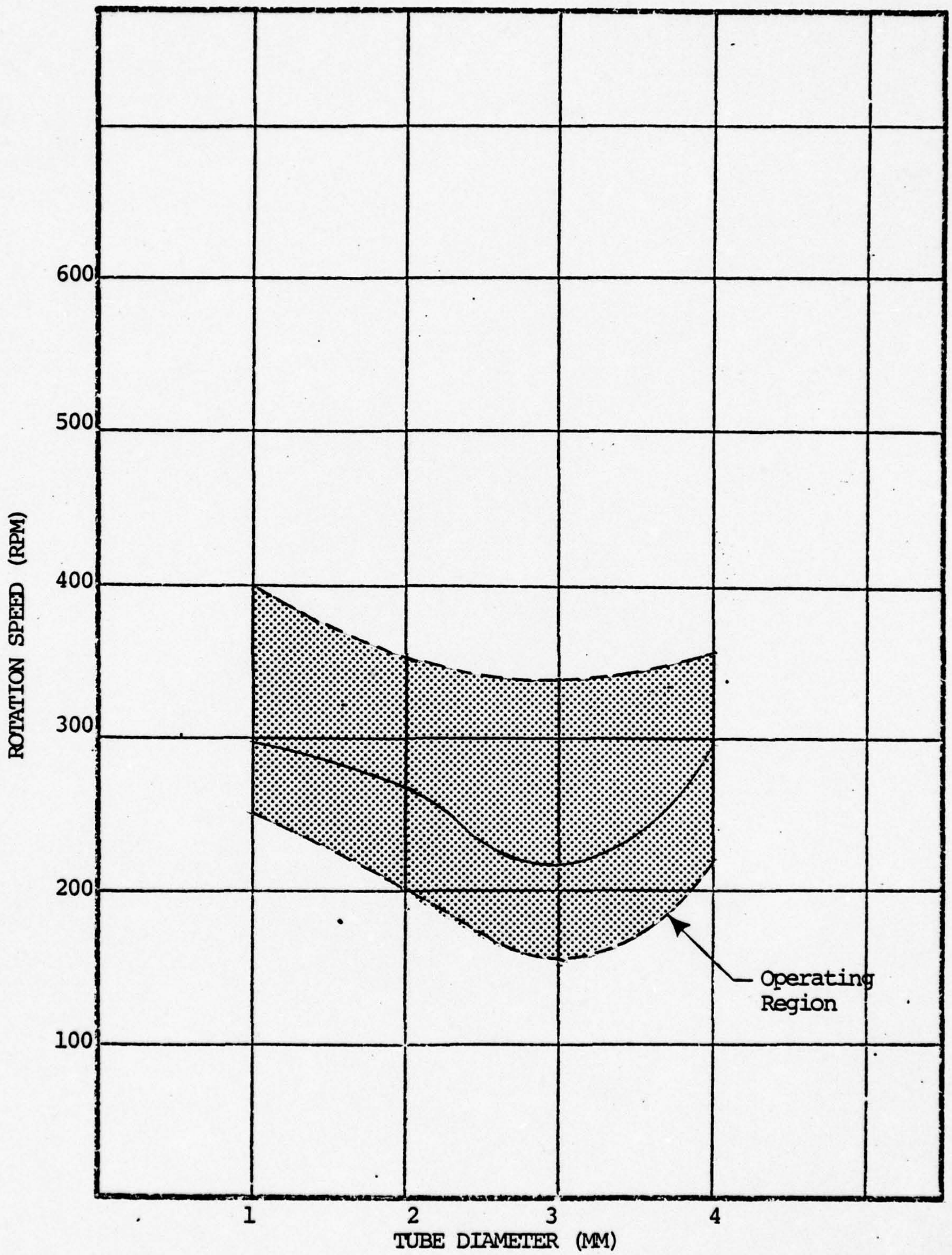

Figure 7. Tube Rotating Device, Rotation Speed Relationship

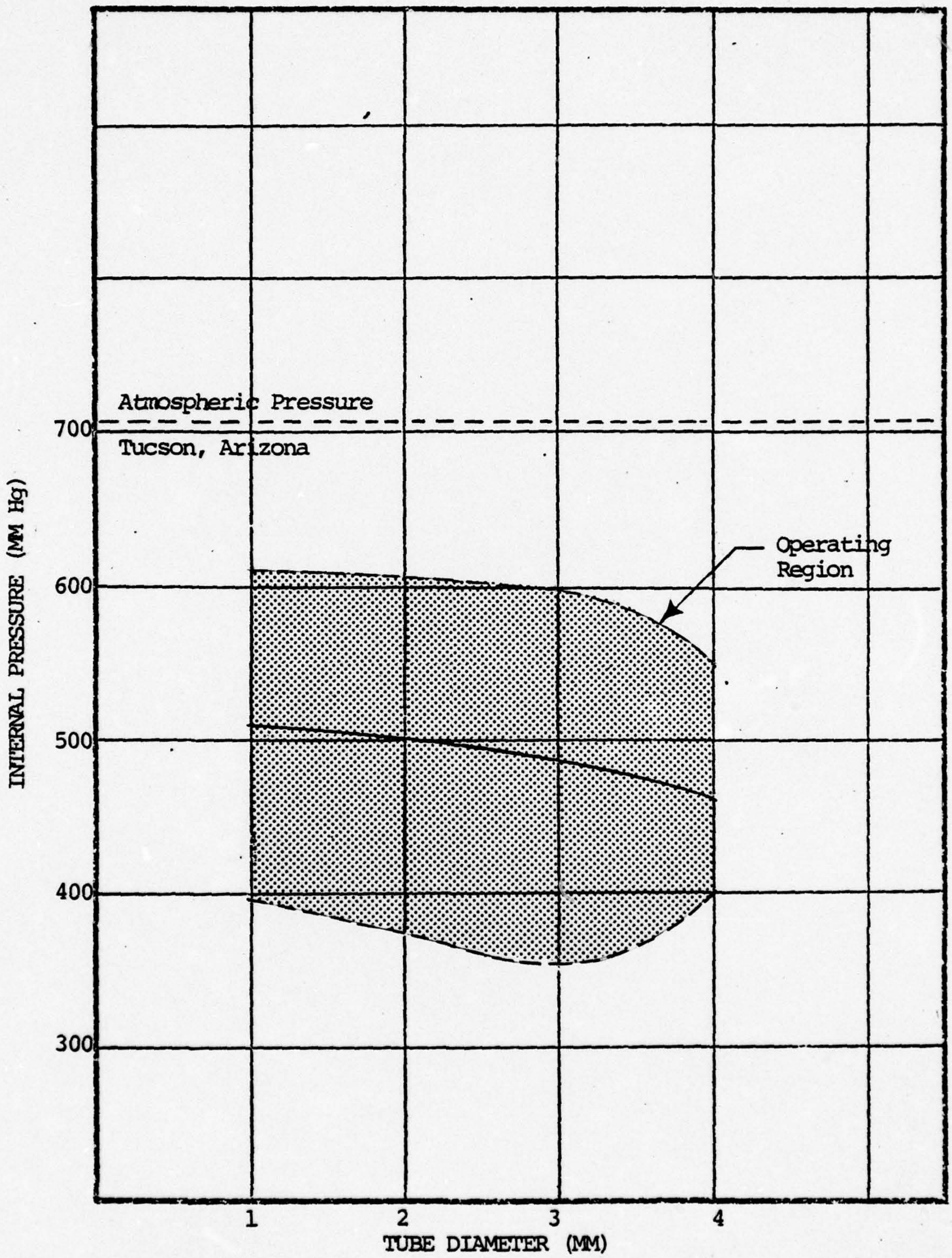

Figure 8. Tube Rotating Device, Internal Pressure Relationship

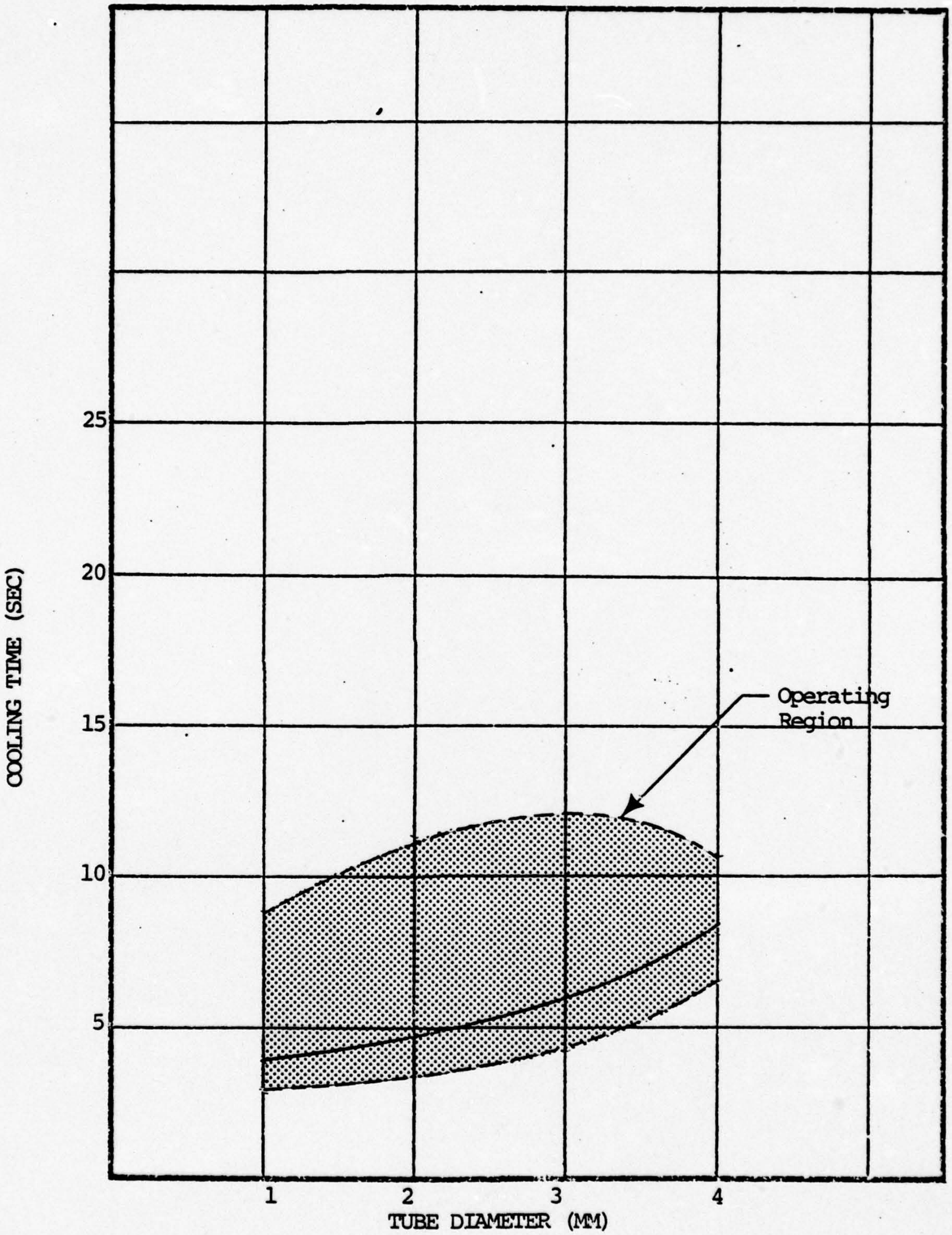

Figure 9. Tube Rotating Device, Cooling Time Relationship

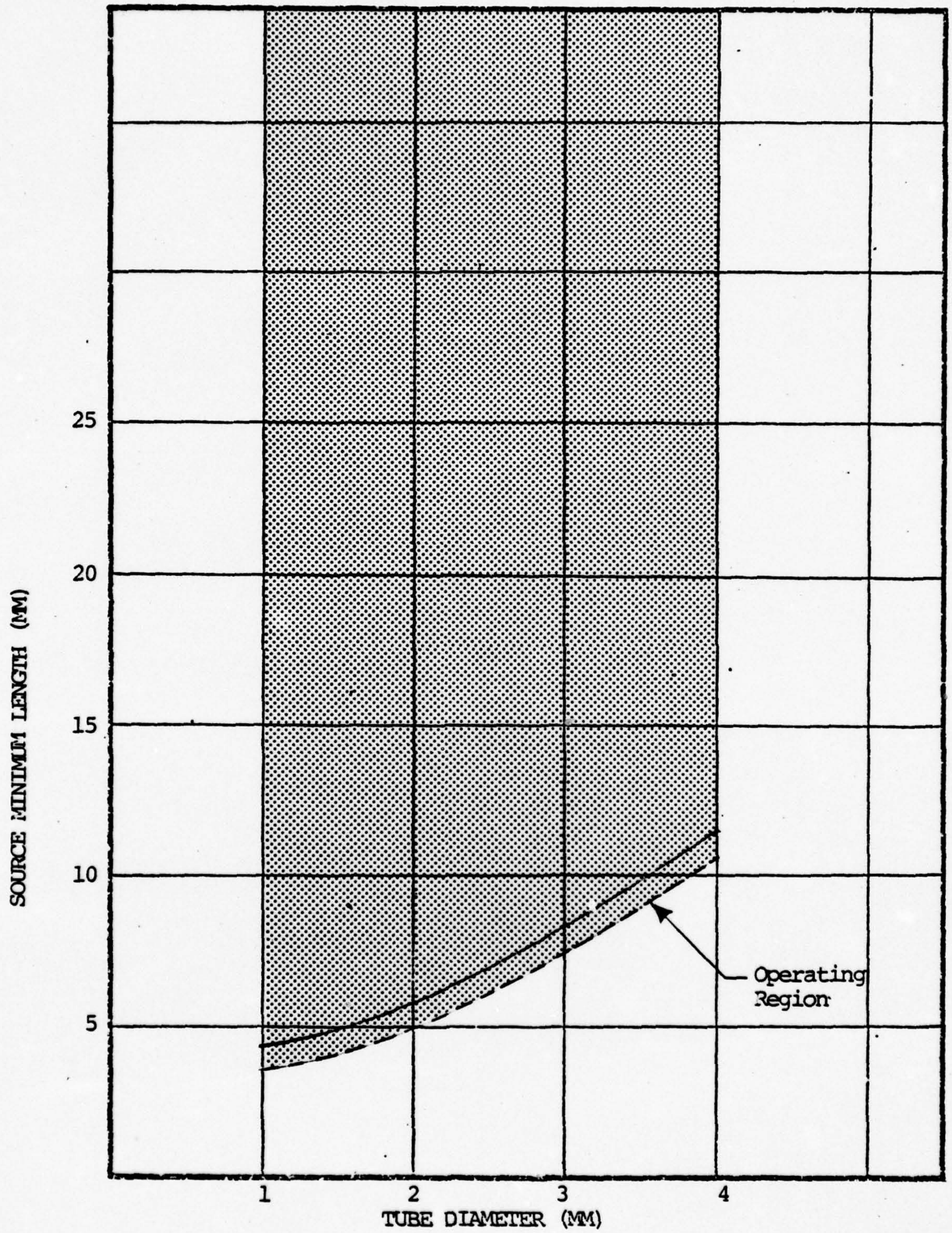

Figure 10. Tube Rotating Device, Source Minimum Length Relationship

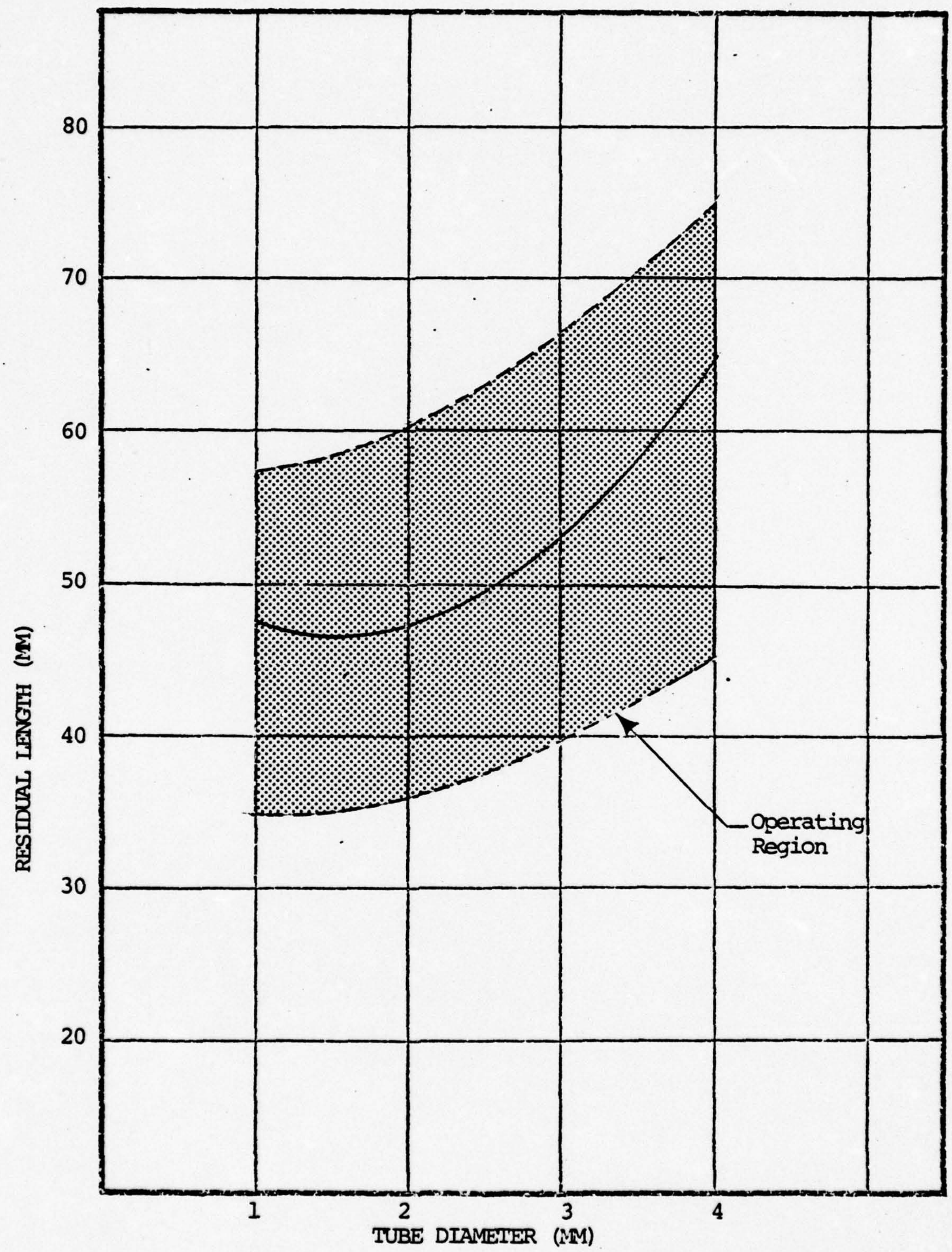

Figure 11. Tube Rotating Device, Residual Length Relationship

4.2.1.5 Oven anneal test optimization. The oven anneal test, an integral part of the production sequence, has a two-fold purpose. The first is to anneal the glass tubes to relieve all strains incurred during manufacture, the second is to remove sources with improper seals by noting a drop in luminance during the visual test (i.e., loss of tritium).

4.2.1.5.1 Process description. Glass light sources from one day's production are accumulated in beakers until the end of a work shift. The oven is turned on and allowed to stabilize at 560°C. The beakers containing the day's production are placed in the oven, after stabilization; and the oven temperature is monitored until it again reaches 560°C. After it reaches temperature, the parts remain for five minutes, when they are removed and left in the hood to cool.

4.2.1.5.2 Process operations.

1. Place radioluminous sources in glass beakers.
2. Turn oven on and allow temperature to stabilize at 560°C.
3. Raise the face of the hood.
4. Open door and place parts in oven and close door.
5. Monitor oven temperature until it reaches 560°C.
6. When it reaches 560°C, time for five minutes.
7. Remove glass parts and allow to cool.

4.2.1.5.3 Outline specification equipment and tools. Two major items of equipment are used in the oven anneal testing: (Also, see equipment specifica-

tions in Appendix B.)

1. Stainless steel laboratory hood.
2. Anneal test oven.

Stainless steel hood:

The hood must be large enough to accommodate the oven and some bench space to allow parts to cool. It also must be able to sustain high temperatures. By using a plenum-blower-stack arrangement, no blower is needed for the hood. The design calculations for exhaust are covered in Appendix D. The hood has dimensions of 96 inches long x 36 inches wide x 40 inches high.

Annealing oven:

The annealing oven must be capable of temperatures of 560°C and be large enough to accommodate at least one day's production of any size or shape of tubes produced. The one used is a Gruenberg Model No. B120C16, complete with controller from Gruenberg Electric Company, Inc., 2021 Beach Road, Williamsport, Pennsylvania.

4.2.1.6 Testing optimization. Testing procedures involve three different types of testing equipment: (1) visual/dimensional testing, (2) luminance testing, and (3) liquid scintillation testing. These are all separate procedures and the equipment is located in different areas. See Fig. 19, Dwg. NR. SK-1204 in Appendix A.

4.2.1.6.1 Process description. Tritium-filled glass light sources are visually and dimensionally tested in an exhaust hood. The visual test is performed on 100% of the manufactured tubes.

Luminance testing is performed by utilizing visual photometers and a special luminance test device which indexes sources past a photometric head. Sources are loaded by hand in wells in the index table and luminance readings noted. Sources are rejected if the luminance reading does not fall within the required tolerance range.

Liquid scintillation testing is performed by soaking individual tubes in a known amount of water then a sample of this water is analyzed by liquid scintillation techniques for tritium content. Sources which test above an acceptable level are rejected. (See Quality Control Manual for details of testing methods.)

4.2.1.6.2 Process operations.

Visual and dimensional testing:

1. Spread sources on trays in hood.

2. Visually examine sources.
3. Measure sources with jigs or tools.
4. Reject nonconforming sources.

Luminance testing:

1. Individually place sources in front of photometric head.
2. Use semi-automatic index table whenever possible.
3. Reject nonconforming sources.

Liquid scintillation testing:

1. Soak sources in water for 24 hours.
2. Using a sample of this water, mix liquid scintillation cocktail.
3. Calibrate liquid scintillation counting equipment.
4. Count samples in liquid scintillation counter.
5. Reject nonconforming tubes.

4.2.1.6.3 Outline specification equipment and tools. The following lists major items of equipment for testing: (Also, see equipment specifications in Appendix B.)

1. Visual and dimensional testing hood.
2. Scanning microphotometer.
3. Semi-automatic luminance testing equipment.
4. Liquid scintillation counter and accessories.

Visual and dimensional test hood:

This hood is a HEMCO Corporation Model No. 20502.

Scanning microphotometer:

This equipment is a Gamma Scientific, Inc., Model No. 2400.

Semi-automatic luminance testing equipment:

This specially designed equipment is manufactured by American Atomics Corporation. It utilizes a Jackson Model No. MNT-8-4 index table and a Photo Research Model No. 1980 Pritchard photometer

Liquid scintillation counter:

This equipment is a Searle IsoCap Model No. 300.

4.2.1.6.4 Results. Optimization results for the luminance test equipment with automatic index table are shown in Figs. 12 through 15. These data were generated for various shaped tritium sources with various luminous levels. The sources were measured for a single spot luminance value, first. Then, they were measured in the luminance test equipment for integrated luminance values and the normalized percentage variation was calculated. From the data, it is shown that practically all of the data points are within $\pm 12\%$ of the spot luminance values. This compares very favorably with the $\pm 25\%$ tolerance range allowable for most production sources.

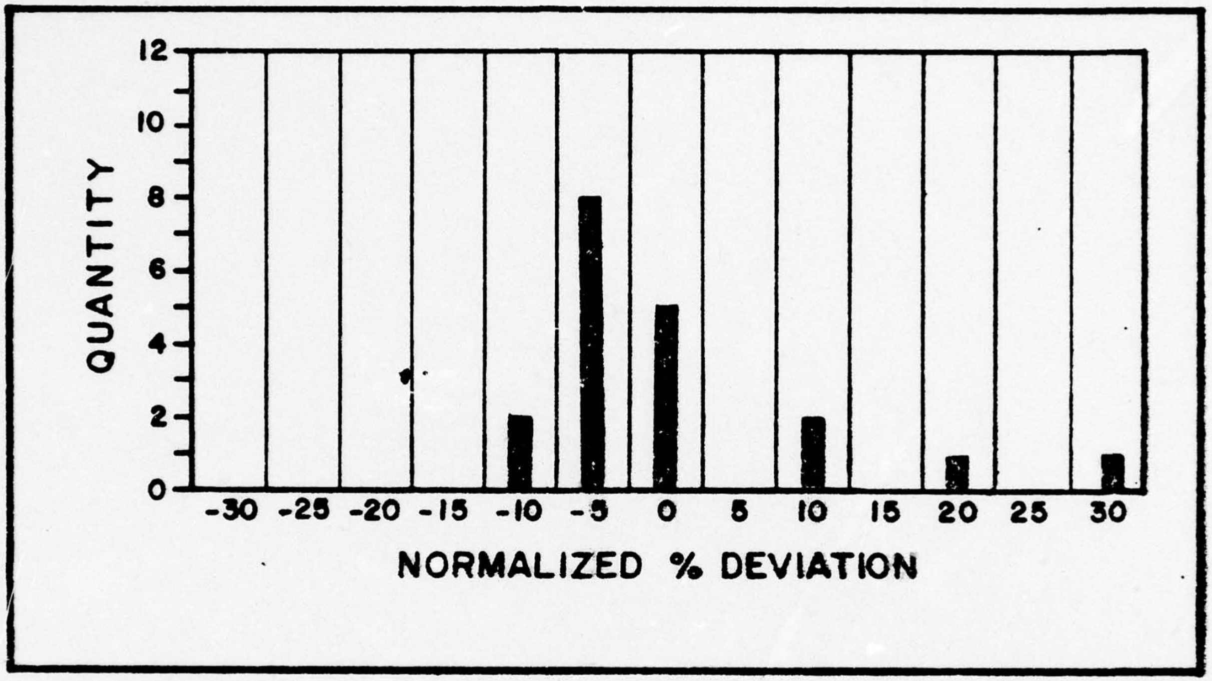

Figure 12. Normalized Percentage Deviation of Integrated Luminance vs Spot Luminance. (1mm OD x 6mm Long Sources)

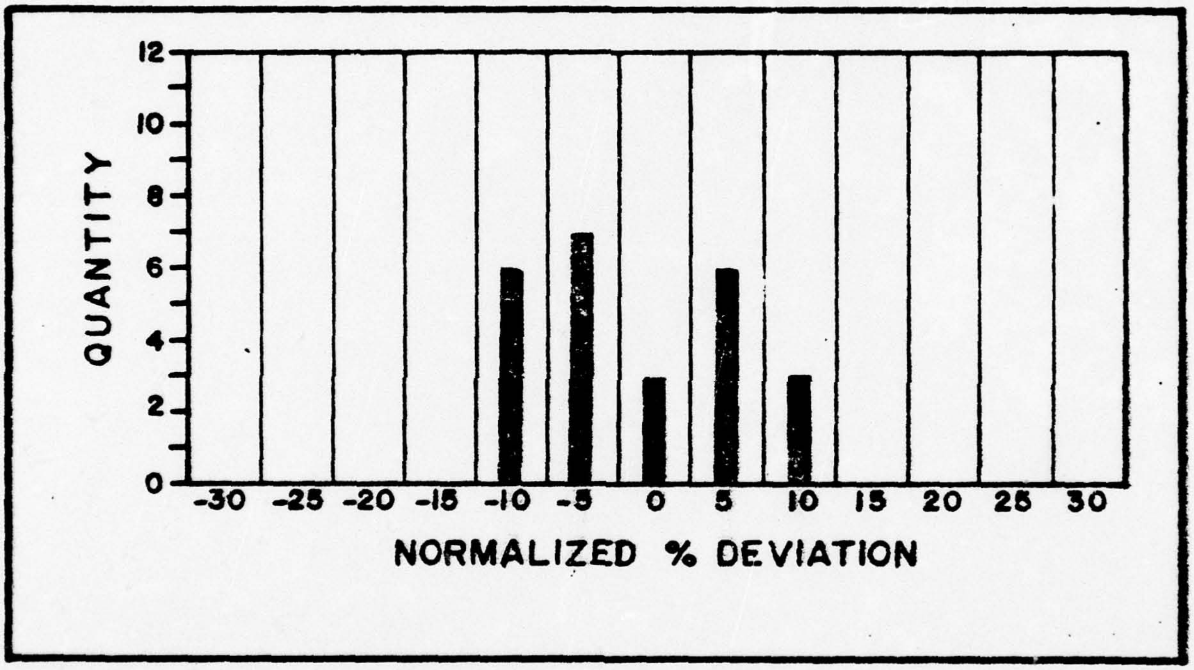

Figure 13. Normalized Percentage Deviation of Integrated Luminance vs Spot Luminance. (2mm OD x 7mm Long Sources)

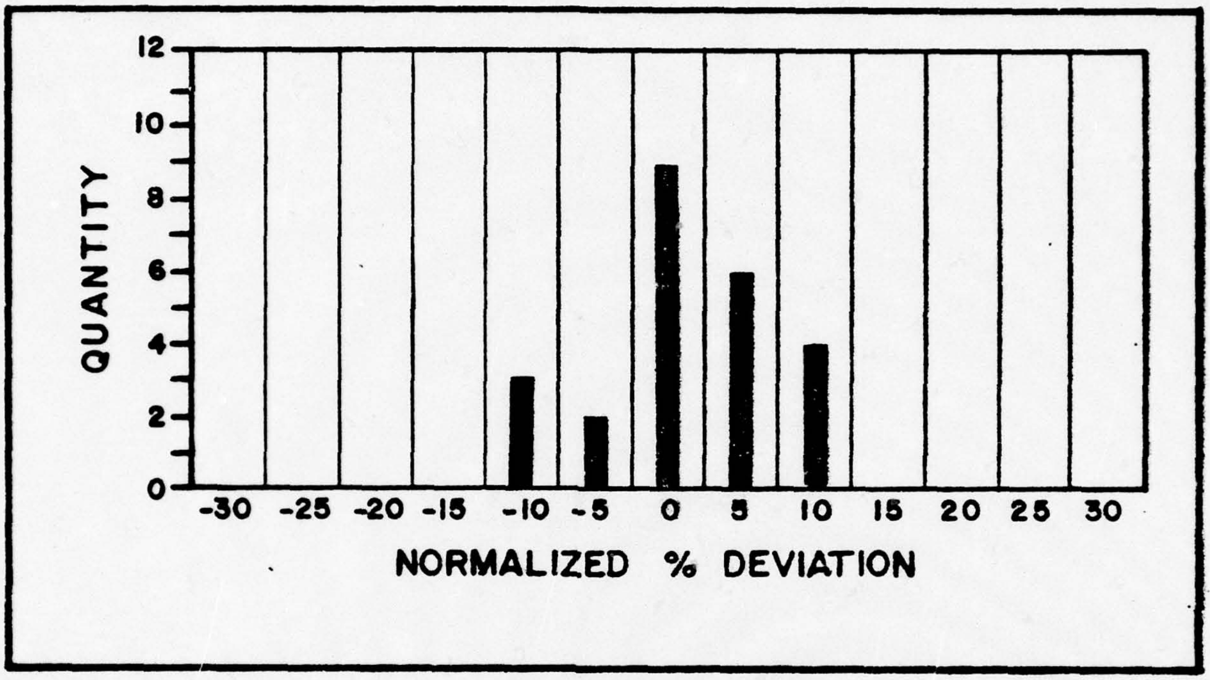

Figure 14. Normalized Percentage Deviation of Integrated Luminance vs Spot Luminance (2mm x 4mm Rectangular Sources)

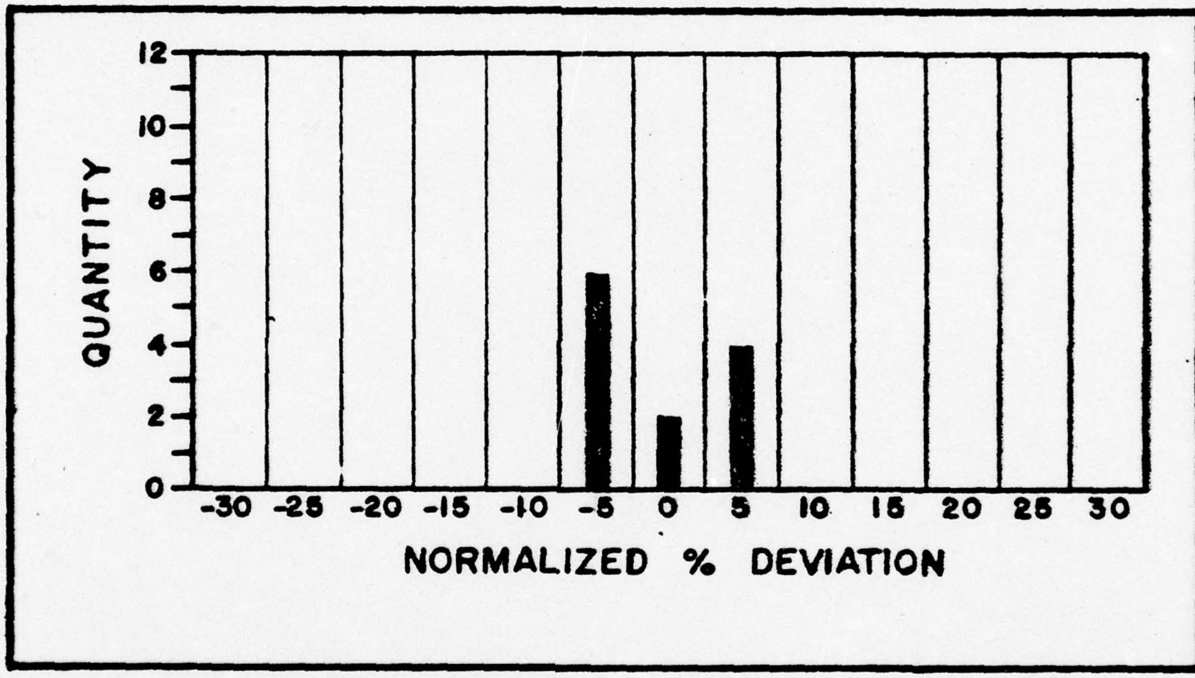

Figure 15. Normalized Percentage Deviation of Integrated Luminance vs Spot Luminance. (2mm x 4mm Curved Rectangular Sources)

In subsequent testing, the percentage deviation was reduced whenever several spot luminance values were measured and the results averaged. This was expected since the integrated luminance values should provide a better indication of source usability than spot luminance values.

The measurement of overall light flux is a special and important aspect of this equipment. The luminance response is an integrated value over the area of measurement (the largest area of measurement is 3.17 inches). This can provide a better test of production source acceptability than spot luminance measurements, since most applications require a satisfactory overall light emission output from each source. The integrated light flux measurement combines the results of dimensional tolerance specifications and luminance tolerance specifications and allows the selection of sources with more uniform overall characteristics. The net effect is that the luminance tolerance range may be increased without changing source applicability or the luminance tolerance range may be tightened without increasing the number of rejected sources by a normally corresponding amount.

The numerical readout of this test equipment provides an exact value for acceptability or non-acceptability. The calibration of the equipment may have a high value and a low value for rejection of sources and, in other cases, may have a single low value, above which all sources are accepted.

4.2.2 Limited production Results. Limited production involved the manufacture of 11,900 tritium light sources per specifications of the Contract Purchase Description. To perform this function, production scheduling methods and material control procedures were developed.

4.2.2.1 Production scheduling. Production scheduling efforts for the full rate production operation are limited to: (a) establishing material control procedures, (b) balance and control of in-line storage quantities in accordance with production rate requirements, and (c) scheduling configuration changes into the production sequence.

Production scheduling involves all procedures required to permit all work stations to operate at peak efficiency. Raw materials must be available as needed. This is simplified by the fact that small quantities of materials produce many units. See Section 4.1.8 for material handling and Section 4.2.2.2 below for the material control procedures.

However, the production system is highly labor sensitive and requires close control of all labor efforts. Labor/production output restrictions are discussed below for all the separate manufacturing steps, relative to the desired production levels per Section 3.1.2.

1. Glass cutting. There are no output restrictions for this operation.

2. Glass shaping and annealing. There are no output restrictions for this operation except for the production of odd shaped parts. For

example, curved rectangular parts (in particular, if the part is curved around the thick section of tubing) will require multiple stations, fixtures, and operators, depending on the quantities involved.

3. Phosphor-coating. There are no output restrictions for this operation.

4. Phosphor-baking. There are no output restrictions for this operation.

5. Storage. There are no output restrictions for this operation.

6. Tritium filling. There are no output restrictions for this operation, except as indicated in Section 4.2.2.1.3 below.

7. Auxiliary glass sealing. Output restrictions for the laser sealing operation are dependent on the number of parts that can be handled on one sealing station (see Section 4.2.1.4). There are no output restrictions for torch sealing by hand, since this may require several stations and operators when odd shaped parts are encountered.

8. Oven anneal test. There are no output restrictions for this operation.

9. Visual/dimensional test. There are no output restrictions for this operation.

10. Luminance test. There are no output restrictions for this operation, except for the possibility of an odd part requirement.

11. Liquid scintillation test. Output capabilities are dependent on sensitivities, specifications, and counting times. Output restrictions may be encountered for particular specifications. In general, the usual specifications allow a throughput of approximately 600 liquid scintillation tests per day. Each test may comprise one tube or several tubes depending on requirements.

12. Storage. There are no output restrictions for this operation.

4.2.2.1.1 Balance and control of in-line storage quantities. On-hand material quantities are listed in Table 2. There are no storage quantity problems due to the small amounts of materials required for manufacturing. Storage of all materials requires only small areas and these storage areas in all cases are located in the manufacturing area where the materials are used. Tritium gas is stored near the tritium filling units. Phosphors are stored in the phosphor-coating area. Ballotini and phosphor-coating chemicals are stored in the phosphor-coating area. Glass tubing is stored in the glass forming area.

4.2.2.1.2 Scheduling configuration changes. Changes in part configuration are easily and quickly handled at all manufacturing steps except glass shaping and tritium filling. Glass shaping may require

Table 2. Raw Materials Listing

Number	Material	Order Quantity*	On-Hand Quantity*
1.	Tritium Gas	5,000 to 10,000 Curies	5,000 to 25,000 Curies
2.	Phosphors, Standard	5 pounds (each type)	5 pounds (each type)
3.	Phosphors, Special	1 pound (each type)	1 pound (each type)
4.	Ballotini	50 to 100 pounds (each size)	50 pounds (each size)
5.	Chemicals (Phosphor-Coating)	1 to 5 pints (each type)	2 pints (each type)
6.	Glass Tubing (Standard Circular)	10 pounds (each size)	10 pounds (each size)
7.	Glass Tubing (Special Circular)	2 to 5 pounds (each size)	2 pounds (each size)
8.	Glass Tubing (Standard Rectangular)	10 pounds (each size)	10 pounds (each size)
9.	Glass Tubing (Special Rectangular)	1 to 2 pounds (each size)	1 pound (each size)

* Or as required for specific production requirements.

from one to four hours to provide a configuration change. This period of time is required to provide adjustments to the equipment and to ascertain part compliance by a trial run. Tritium filling may require from one to six hours to provide for a change in configuration. This period of time is required to change compression fittings, to change tritium supply filling volumes, and to adjust tritium pressures. See Section 4.2.2.1.3 below.

4.2.2.1.3 Tritium gas scheduling. Production scheduling for tritium gas requires special techniques. Individual source fillings may range in activity level from two curies down to two millicuries. This fact requires large variations in the storage capabilities of tritium in both the bulk storage area and the tritium filling machines themselves. At two curies per source and under full production, bulk tritium deliveries will have to be made every few days. Any disruption in deliveries would cause a lag in production capabilities.

Also, when sources are filled at two curies each, the pyrophoric containers on the filling machines must be capable of maintaining a sufficient inventory of tritium during tritium filling operations. If these pyros have too small a reserve of tritium, down-time for refilling operations would become excessive.

If large production requirements with sources filled to maximum amount of tritium are experienced, the procedure would be to use a network of pyros with facilities for routine changing of spent pyros without stopping filling operations. As the general case,

the replenishment of tritium under these circumstances, requires special considerations and production scheduling must provide time and facilities for these efforts.

4.2.2.2 Material control procedures. Material control procedures will undergo modification as the operations require. Higher levels of inventory were stocked during start-up operations for particular source configurations until actual requirements were determined. Actual performance in the areas of production, delivery, quality and in-house experience in inventory control will determine the extent of these modifications, for source requirements not yet experienced.

Material storage is the place designated as storage for each particular manufacturing area except for tritium which is stored under a hood as shown on the floor plan. (See Figure 19, Drawing No. SK-1204). Records are maintained on scrap material and parts so as to facilitate analysis and balance inventories.

All materials purchased must meet the basic quality control standards set up in the Quality Control Manual for incoming materials. A qualified vendors list for major materials is shown in Table 3.

4.2.2.2.1 Stock levels. Stock levels for raw materials are as indicated in Table 2. The on-hand quantity here is an average value and changes may be required for special manufacturing requirements (for example, tritium gas supplies for filling of maximum activity sources.)

Table 3. Qualified Vendors List For Major Materials

Number	Item	Vendor
1.	Tritium Gas	Oak Ridge National Laboratory - Oak Ridge, Tenn.
2.	Phosphors (Standard and Special)	U. S. Radium Corporation Morristown, N.J.
		Levy-West London, England
		General Electric Nela Park, Ohio
		Sylvania Towanda, Pa.
		Diehl and Company Staad, West Germany
3.	Ballotini	Microbeads Division, Cataplate Corporation Jackson, Miss.
		Brandhurst Company Ltd. High Wycombe, England
4.	Chemicals (Phosphor-Coating)	Mallinckrodt Chemical Co. St. Louis, Mo.
5.	Glass Tubing (Standard and Special Circular)	VWR Tucson, AZ.
		Owens-Illinois Toledo, Ohio
		Corning Glass Works Corning, N.Y.
6.	Glass Tubing (Standard and Special Rectangular)	Wilmad Glass Co, Inc. Buena, N.J.
		Fisher and Porter Co. Warminster, Pa.
		Vitro Dynamics P.O. Box 285 Rockaway, New Jersey

4.2.2.2.2 Shipping increments. Shipping increments for raw materials are as indicated in Table 2. Again, the order quantity is an average value, and may have to be changed for special requirements.

4.2.2.2.3 Scheduling in-house material inventory. In-house material inventories are taken on a monthly basis with the individual section supervisors responsible for documenting this inventory. Since all raw materials are stored in the particular use area, this inventory actually takes the form of a running inventory and as such, the section supervisors are constantly aware of the amount of materials on-hand. Changes in the configuration of manufactured items must take into account the lead times for the purchase of materials, see Table 1. It is the responsibility of the Manager of Tritium Operations to schedule material purchases far enough in advance to satisfy the current lead times.

4.2.2.2.4 Waste. Waste from this manufacturing facility is composed of two categories: (1) radioactive waste, and (2) non-radioactive waste. Radioactive waste contains out-of-specification sources (which are sealed), liquid scintillation materials, swabs, broken source particles, broken sources from the oven-anneal test, and tritium contaminated materials such as pump oils. Sources which do not meet specifications for luminance and/or dimensions but which do pass liquid scintillation testing, will be used for other purposes of disposed of according to current company policy. All other radioactive waste is disposed of according to Federal NRC requirements, State requirements and DOT requirements.

Non-radioactive wastes contain the following: glass tubing scrap, phosphor-ballotini mix, scintillation chemicals, solvents, and cleaning chemcals. All of these items are disposed of according to current company policy.

Before disposal, all waste is logged in a waste disposal form in order to complete data on a material balance. Incoming materials shall equal manufactured products plus estimated waste materials.

4.2.2.2.5 Materials storage. All raw materials are stored in the areas where they are used for manufacturing operations.

4.2.2.2.6 Material acquisition. The acquisition of materials from suppliers is according to the current qualified vendors list, see Table 3. The quantities of materials per order are listed in Table 2 .

4.2.2.2.7 Material control listing. A material control listing is on hand for use by the Manager of Tritium Operations. The basis for this listing is a current inventory listing for materials by section supervisors. The material control listing enables the Manager of Tritium Operations to schedule future requirements and to anticipate the scheduling of special requirements.

4.2.2.2.8 Material receiving schedule. The material receiving schedule follows the composite time span produced by integrating the production lead time from Table 1 and the raw materials order

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quantities from Table 2. Receiving log, receiving inspection, and material specification requirements are all contained in the Quality Control Manual.

4.2.2.3 Limited source production. The contract purchase description required the manufacture of 11,900 tritium light sources as follows:

1.	Straight tube, 2 mm in diameter by 7 mm long, luminosity 30-50 microlamberts	3,000
2.	Straight tube, 1 mm in diameter by 6 mm long, luminosity 30-50 microlamberts	3,000
3.	Rectangular tube, 4 mm by 8 mm and 2 mm thick, luminosity 30-50 microlamberts	3,000
4.	Curved rectangular tube, cross-section 2 mm by 4 mm having an arc of 50 degrees and inside edge is on a 15.24 mm radius, luminosity 50-90 microlamberts	1,500
5.	Flat luminous area 2 cm by 2 cm and 3 mm thick, luminosity 50-90 microlamberts	100
6.	Flat luminous area 2 cm by 2 cm and 3 mm thick, luminosity 90 microlamberts	100

7.	Flat luminous area 2 cm by 2 cm and 3 mm thick, luminosity 130 microlamberts	100
8.	Flat luminous area 2 cm in diameter and 3 mm thick, filled at 800 mm of mercury.	50
9.	Flat luminous area 2 cm in diameter and 3 mm thick, filled at 1,600 mm of mercury	50
10.	Straight rectangular tube 2 mm by 2 mm and 4 mm long, luminosity 50 microlamberts	1,000
	TOTAL	11,900

In addition, a diffusion test (liquid scintillation) was required for these sources as follows:

"An individual 24-hour water diffusion test will be conducted on five percent of the sources produced. The balance of the sources will be accepted on group water diffusion test. For the individual samples, diffusion rates greater than 50 nanocuries/day will be rejected; for group testing the rejection of the group will be 50 nanocuries/day times the square root of the number of vials in the group."

5.0 FACILITY ORGANIZATION

The organization and manpower requirements, which provide an effective and efficient operating unit, follow below. Functional organizational charts, with summary descriptions defining the responsibilities of the positions, are included.

5.1 ORGANIZATION

Fig. 16 shows the planned organization for Tritium operations. The skill level for each labor classification has been developed based on the evaluation of skill, experience, responsibility, education and other elements which indicate contribution and effort required. See Table 4 for skill levels and training commitments required.

Manpower requirements to produce tritium-filled glass light sources are presented in Table 5. The manpower requirements reflect an average plant operating condition; and specifically a source production requirement of the types specified for limited production (total of 11,900 sources). Other source configurations, or special source requirements, may change labor concentrations and/or total plant manpower.

5.1.1 Position responsibilities. Position responsibilities for the plant organization for Tritium operations follow:

1. Manager, Tritium operations.

Responsible for all tritium source manufacturing operations, for supervision of all manufacturing section supervisors, for scheduling

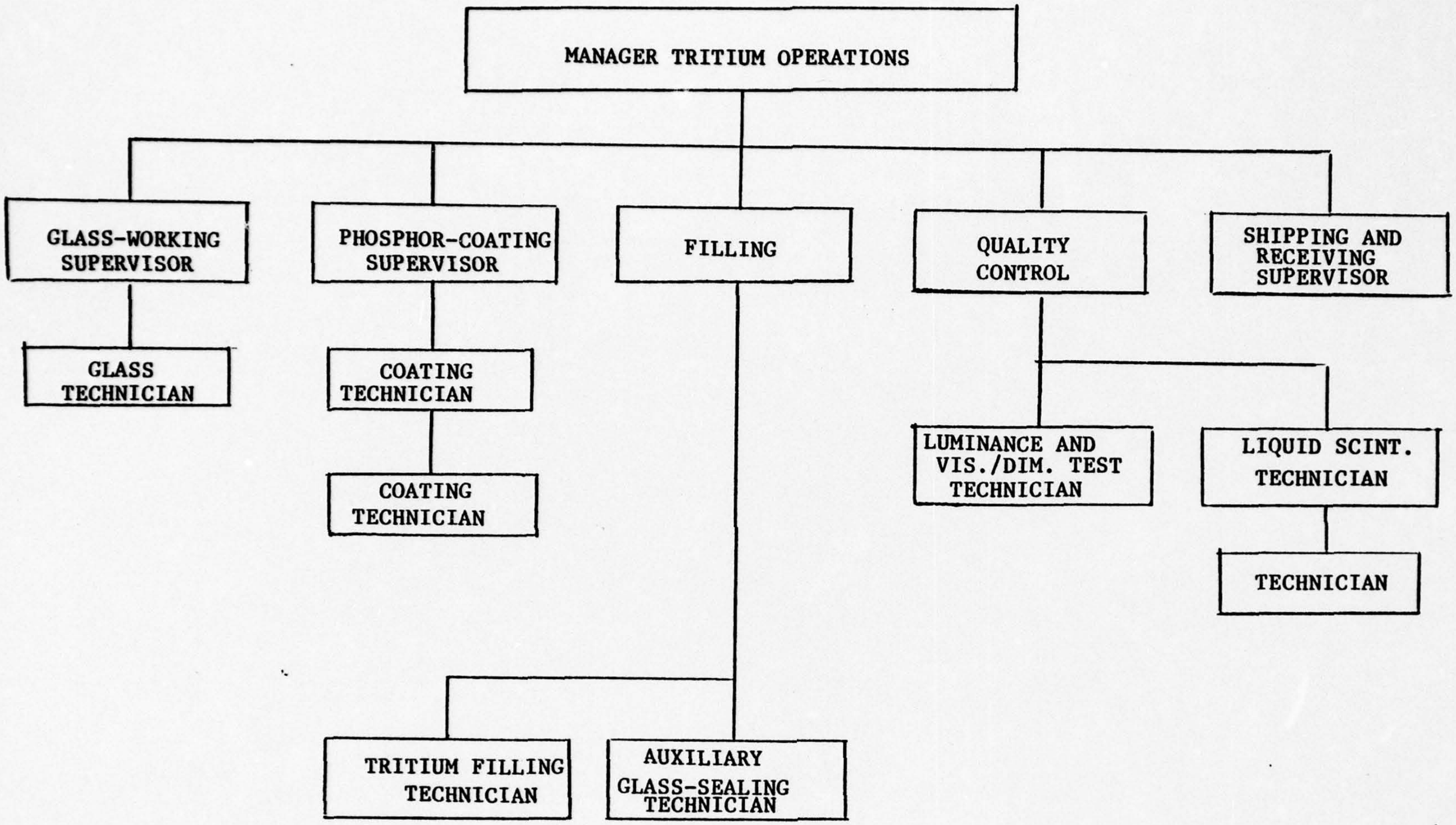


Figure 16 Planned Organization - Tritium Operations

of all manufacturing operations, for order acceptances, for product deliveries, for special source designs and scheduling, for documentation required by management or by standard engineering procedures, for accountability of parts and radioactive materials, for quality assurance requirements of Quality Control Manual for Tritium Operations in conjunction with the Quality Control Officer for radiation protection requirements of the facility's Radiation Protection Program in conjunction with the Radiation Safety Officer, for upgrading tritium operations, and for other management directives.

2. Glassworking supervisor.

Responsible for all glassworking and forming operations, for production to tolerance of all glass parts, for conformance to all applicable specifications and standard engineering procedures, and for other directives by the Manager, Tritium Operations.

3. Phosphor-coating supervisor.

Responsible for all phosphor-coating operations, for part production in accordance with specifications and standard engineering procedures, and for other directives by the Manager, Tritium Operations.

4. Source manufacturing supervisor.

Responsible for tritium source filling operations, for documentation required by standard engineering procedures, for accountability of parts and radioactive materials, for radiation protection and

industrial safety requirements, for calculations for all source fillings, and for other directives by the Manager, Tritium Operations.

5. Quality Control Supervisor

Responsible for all testing operations required for source production, for part testing in accordance with specifications and standard engineering procedures, and for other directives by the Manager, Tritium Operations.

6. Shipping and receiving supervisor.

Responsible for all parts shipping and materials receiving, for maintenance of all required records, for accountability procedures required by specifications or standard engineering procedures, and for other directives by the Manager, Tritium Operations.

7. Process technicians.

Responsible for completing required training programs, for production requirements as specified, and for other directives by section supervisors.

5.1.2 Training. On-the-job training requirements for operating personnel are indicated in Table 4. Hours of actual on-the-job training are logged for each employee.

5.2 Manpower requirements. The summary manpower requirements are shown in Table 5. These may change or be adjusted for other production requirements.

Table 4. Skill Levels and Training.

Number	Skill Level	Backbround Training	On-the-Job Training
1.	Supervisor-Grade 3	Engineering Degree. Nuclear Training in Radiation Safety, Health Physics and Isotope Handling. 2-3 yrs. exper.	1 - 2 Months
2.	Supervisor-Grade 2	Engineering or Science Degree, or Undergraduate with extensive applicable training in Radiation Safety, Health Physics, and Isotope Handling.	4 Weeks
3.	Supervisor-Grade 1	Applicable Technical Courses.	3 Weeks
4.	Technician-Grade 3	None.	4 Weeks
5.	Technician-Grade 2	None.	2 Weeks
6.	Technician-Grade 1	None.	1 Day

Table 5. Manpower Requirements

Number	Job Description	Skill Level	Number Required
1.	Manager Tritium Operations	Supervisor-Grade 3	1
2.	Quality Control Supervisor	Supervisor-Grade 2	1
3.	Operations Supervisors a. Glass Working b. Phosphor-Coating c. Filling d. Shipping & Receiving	Supervisor-Grade 1	3
4.	Operations Technicians a. Glass b. Coating c. Tritium-Filling d. Auxiliary-Sealing e. Luminance Testing f. Liq. Scint. Testing	Technician-Grade 3	6
5.	Operations Technicians a. Coating b. Filling c. Testing	Technician-Grade 2	3
6.	Operations Technicians a. Testing	Technician-Grade 1	2
		TOTAL	16

They do represent an average requirement for the limited production contract requirements (11,900 sources).

6.0 PROBLEM AREAS

6.1 Equipment Delivery. The following items of equipment had delivery delays of approximately six months beyond the original estimated delivery dates: rotary tritium filling machines, glassworking machines, and stainless steel hoods.

The basic reason for the tritium filling machine delay was that this equipment, being new and specifically designed for this application, was underestimated for delivery by the manufacturer. This would not be the case in the future, if similar equipment were ordered, since the manufacturing details now are well defined and any estimated delivery dates would be firm.

There was no reason for the delivery delay for the glassworking equipment . It merely was not required earlier than the tritium filling machines and, therefore, was not delivered until the same time frame as for the tritium filling machines. It can be anticipated that any future orders for glassworking equipment would be as estimated on order.

The delivery delay for the stainless steel hoods was due to the availability of the stainless steel used in their manufacture. On future orders the manufacturer should provide a firm delivery date based on the actual stocks on hand. The manufacturer of the stainless steel hoods was remiss, also, in that the hoods did not conform to the specifications of the order andhad to be modified after delivery.

6.2 Facilitv Modifications. Facility modifications prior to equipment installation were required after it was decided to locate these tritium operations on the groundsof American Atomics Corporation, Tucson, Arizona. Since these modifications were rather extensive in nature, they resulted in some difficulties in the overall integration of efforts during the construction phase. However, further delays beyond those indicated above in Section 6.1, were not experienced.

The modifications of other facilities or the construction of new facilities, of course, would present different coordination problems. The primary requirement is that all utilities, and all systems be completed prior to equipment installation.

All equipment specifications and utility requirements for this project are contained in Appendix B.

6.3 Drawing requirements. A special problem concerning the submission of required drawings was experienced, in that many of the drawings from Brandhurst Company Limited were not suitable for third generation microfilm reproduction. Certain portions ofthe drawings faded out upon reproduction, and this was not obvious by looking at the original vellum copies. Inked vellum drawings were purchased from Brandhurst Co. Ltd. with delivery completed in April, 1976.

7.0 Costs

7.1 Equipment costs. Dollar values of Government Furnished Equipment at the time of purchase for this project are listed in Table 6. Costs not considered are delivery costs, installation costs, plant modification cost, costs for other facilities already in place, and organizational costs.

8.0 Conclusions

8.1 The equipment and procedures described in this report enabled the manufacture of the tritium radioluminous sources specified in Phase II of the contract.

8.2 The capabilities of the tritium filling machines are such that a fully trained operator of the sixteen-position machine can fill 300 sources per hour. A fully trained operator of the six-position filling machine can fill 100 curved or rectangular sources per hour. Single seal-off tubes can be filled on the six-position machine at 120 per hour.

8.3 The following tritium luminous sources were sealed using the laser technique.

8.3.1 Straight tube 2mm in. diameter by 7mm long, luminosity, 30-50 microlamberts

8.3.2 Straight tube, 1mm in. diameter by 6mm long, luminosity, 30-50 microlamberts

8.3.3 Straight rectangular tube, 2mm X 2mm and 4mm long, luminosity, 50-100 microlamberts

8.4 Attempted Use of Laser Technique on Other Source Shapes

Development efforts during the time allotted on the contract were not completely successful in effecting laser seals on other glass units such as a rectangular tube 4mm X 8mm and 2mm thick and a curved rectangular tube, cross section 2mm X 4mm, having an arc of 50 degrees.

In the case of the curved rectangular tube, non- linear sealing was attempted with the oscillating laser fixture. Hand constricted

straight & curved rectangular tubes were utilized. Partial sealing without cutoff was the result. The reasons for the result are thought to be defocusing of the beam--systematic of the oscillating fixture and non-symetrical glass configuration in the seal-off area.

8.5 The luminance and liquid scintillation measurement systems met the design specifications.

8.6 Quality Control

In Phase II the number of rejects in each step of the source fabrication was related to the learning curve of the technician involved and the performance of the related equipment. The skills required for each production operation were developed during the course of the work.

In Table 7 are listed the estimated percentage rejection levels experienced during operations in Phase II. Table 8 projects rejection losses in future production of those types of tritium luminous sources listed in Table 7 following modification of the tritium filling equipment and subsequent optimization as noted under Recommendations, Sec. 9.

9.0 Recommendations

9.1 A manually loaded, automatically indexed, pressurized, rotary laser sealing system should be designed, constructed and installed on a bearing, non-vibrating surface.

9.2 Further effort should be expended on laser sealing of both linear and non-linear sources using the equipment in 9.1.

9.3 The tritium filling machine pressure regulator should be improved. This will enable closer control of the luminance generated in each source.

9.4 Further optimization is needed, utilizing the modified equipment noted in (1) and (3), with limited production of glass sources of less than 4.5mm dia. or width as well as other types of sources involving the use of the glass working machines.

9.5 Additional photometric tests are needed to examine the correlation of the luminance values obtained for small areas on tritium luminous less than 4mm dia. or width, to complete inclusion of the luminous area of the tubes in a large spot area. With close dimensional control given by the laser cutoff the correlation should be good. After the correlation has been established the luminance testing of the small tubes will be enhanced.

9.6 The use of a microprocessor and a luminance feedback leg will improve luminance measurement of production quantities of sources.

Table 6. Dollar Value of Government Furnished Equipment At the Time of Purchase

Number	Item	Value
1.	Stainless Steel Hoods	$ 12,200.00
2.	16-Position Rotary Index Filling Machine	31,250.00
3.	6-Position Rotary Index Filling Machine	12,500.00
4.	Glass-Working Equipment (2)	35,400.00
5.	Laboratory Benches	2,520.00
6.	Tritium Monitors	17,195.00
7.	Special Tooling	3,800.00
8.	Vacuum Pumps	610.00
9.	Anemometer	435.00
10.	Laboratory Chairs	655.00
11.	Glass Lathe	2,210.00
12.	Glass-Annealing Furnaces	3,275.00
13.	Baking Oven	2,137.00
14.	Tube Oven	1,140.00
15.	Oven-Anneal Test Equipment	2,425.00
16.	Tritium Exhaust Blowers	1,500.00
17.	He-Mass Spectrometer Leak Detector	7,397.00
18.	Laser Tooling	3,500.00
19.	Luminance Test Equipment	6,250.00
20.	Small Equipment and Supplies	5,000.00
21.	Special Mountings	2,000.00
22.	Liquid Scintillation Equipment	12,350.00
23.	Liquid Nitrogen Containers	1,350.00
24.	Fiberglass Hoods	3,308.00
25.	Laser Sealing Equipment	13,035.00
26.	Abrasive Glass Saw	363.00
27.	Gas Burners	230.00
28.	Stereo Microscope	245.00
29.	Glass Tube Storage Rack	225.00
30.	Phosphor-Coating Equipment	336.00
31.	Photometric Equipment	6,280.00
32.	Laboratory Carts	303.00
33.	Vacuum Manipulators	100.00

Table 7

Estimated Rejection Losses During Fabrication of Tritium Luminous Sources in Phase II

A. Basic Operations

Basic Operations	Percent Rejection
Incoming Inspection of Glass	1
Phosphor Coating of Glass	5
Breakage of Glass Sources During Tritium Filling Operations	5

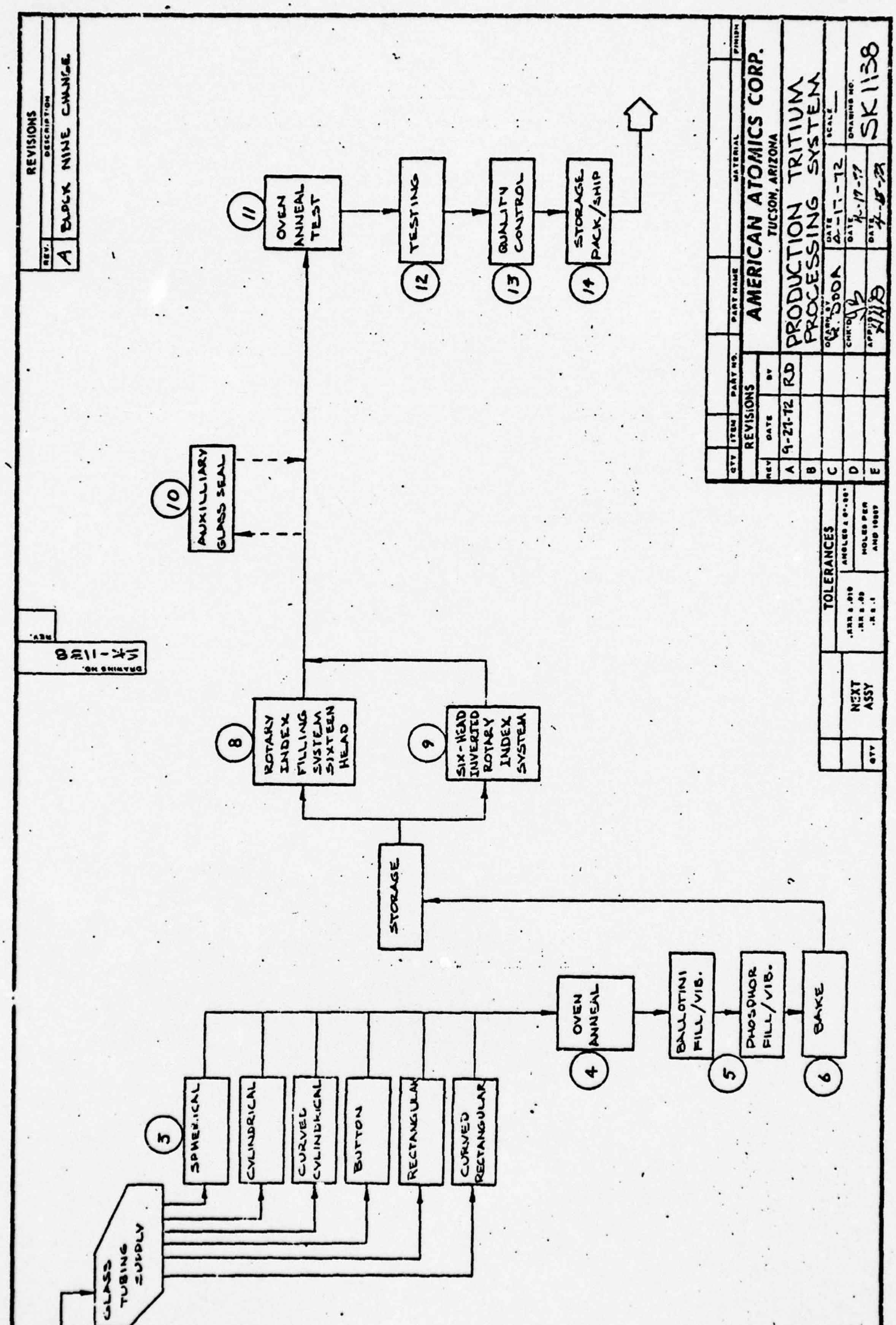
B. Source Fabrication

Type Source	Percent Rejection		
	Dimension	Luminance	Soak Test
2AA 2mm dia.	10	11	20
2AB 1mm dia.	10	25	26
2AC 2mm X 4mm	5	25	25
2AD Curved rectangular	5	30	30
2AK 2mm X 2mm	5	20	15

Table 8

Projected Rejection Losses in Future Production of Sealed Tritium Luminous Sources

Operation	Percentage Loss				
	2mm dia. 2AA	1mm dia. 2AB	2mm X 4mm 2AC	Curved Rect. 2AD	2mm X 2mm 2AK
Glass Working	1	1	1	3	1
Phosphor Coating	4	10	4	5	4
Tritium Filling	1	1	1	4	1
Glass Sealing	5	5	5	5	5
Deminsional Check	2	2	2	5	2
Luminance Test	5	5	5	10	5
Soak Test	5	5	5	15	5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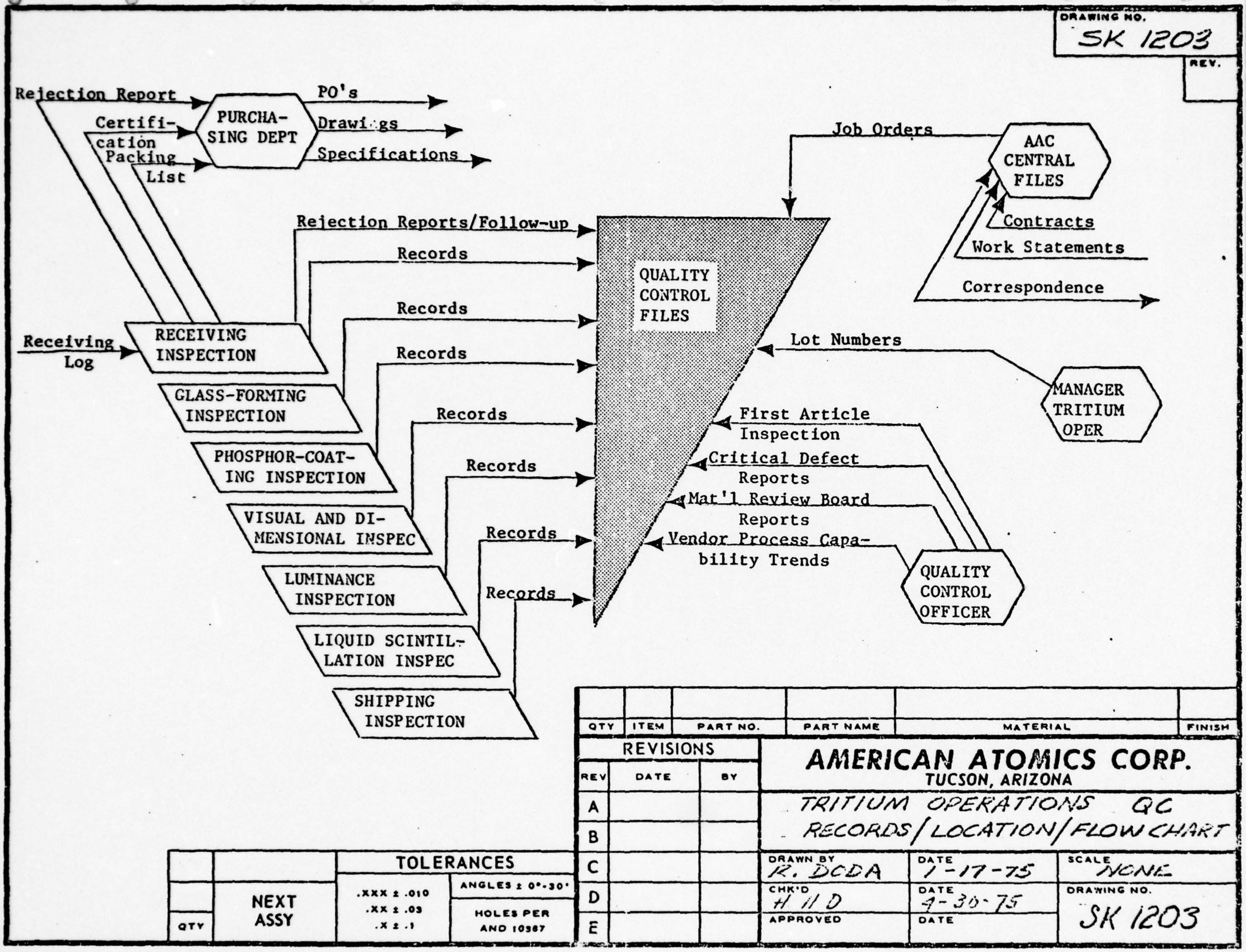
REV.
DESCRIPTION
A BLOCK NINE CHANGE
GLASS TUBING SUPPLY
3
SPHERICAL
CYLINDRICAL
CURVED CYLINDRICAL
BUTTON
RECTANGULAR
CURVED RECTANGULAR
4
OVEN ANNEAL
5
BALLOTINI FILL/VIB.
PHOSPHOR FILL/VIB.
6
BAKE
STORAGE
8
ROTARY INDEX FILLING SYSTEM SIXTEEN HEAD
9
SIX-HEAD INVERTED ROTARY INDEX SYSTEM
10
AUXILLIARY GLASS SEAL
11
OVEN ANNEAL TEST
12
TESTING
13
QUALITY CONTROL
14
STORAGE PACK/SHIP
DRAWING NO.
SK-1138
REV.
TOLERANCES
NEXT ASSY
QTY
REVISIONS
REV
DATE
BY
A
9-27-72
RD
B
C
D
E
QTY
ITEM
PART NO.
PART NAME
MATERIAL
FINISH
AMERICAN ATOMICS CORP.
TUCSON, ARIZONA
PRODUCTION TRITIUM PROCESSING SYSTEM
DRAWN BY
CHK'D
APP'D
DATE
6-17-72
SCALE
DRAWING NO.
SK1138

Fig. 17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SK 1203
REV.
Rejection Report
Certifi-
cation
Packing
List
PURCHA-
SING DEPT
PO's
Drawi:gs
Specifications
Receiving
Log
RECEIVING
INSPECTION
GLASS-FORMING
INSPECTION
PHOSPHOR-COAT-
ING INSPECTION
VISUAL AND DI-
MENSIONAL INSPEC
LUMINANCE
INSPECTION
LIQUID SCINTIL-
LATION INSPEC
SHIPPING
INSPECTION
Rejection Reports/Follow-up
Records
Records
Records
Records
Records
Records
Records
QUALITY
CONTROL
FILES
Job Orders
AAC
CENTRAL
FILES
Contracts
Work Statements
Correspondence
Lot Numbers
MANAGER
TRITIUM
OPER
First Article
Inspection
Critical Defect
Reports
Mat'l Review Board
Reports
Vendor Process Capa-
bility Trends
QUALITY
CONTROL
OFFICER
QTY
ITEM
PART NO.
PART NAME
MATERIAL
FINISH
REVISIONS
REV
DATE
BY
A
B
C
D
E
AMERICAN ATOMICS CORP.
TUCSON, ARIZONA
TRITIUM OPERATIONS QC
RECORDS/LOCATION/FLOW CHART
DRAWN BY
R. DCDA
DATE
1-17-75
SCALE
NONE
CHK'D
H II D
DATE
4-30-75
DRAWING NO.
SK 1203
APPROVED
DATE
TOLERANCES
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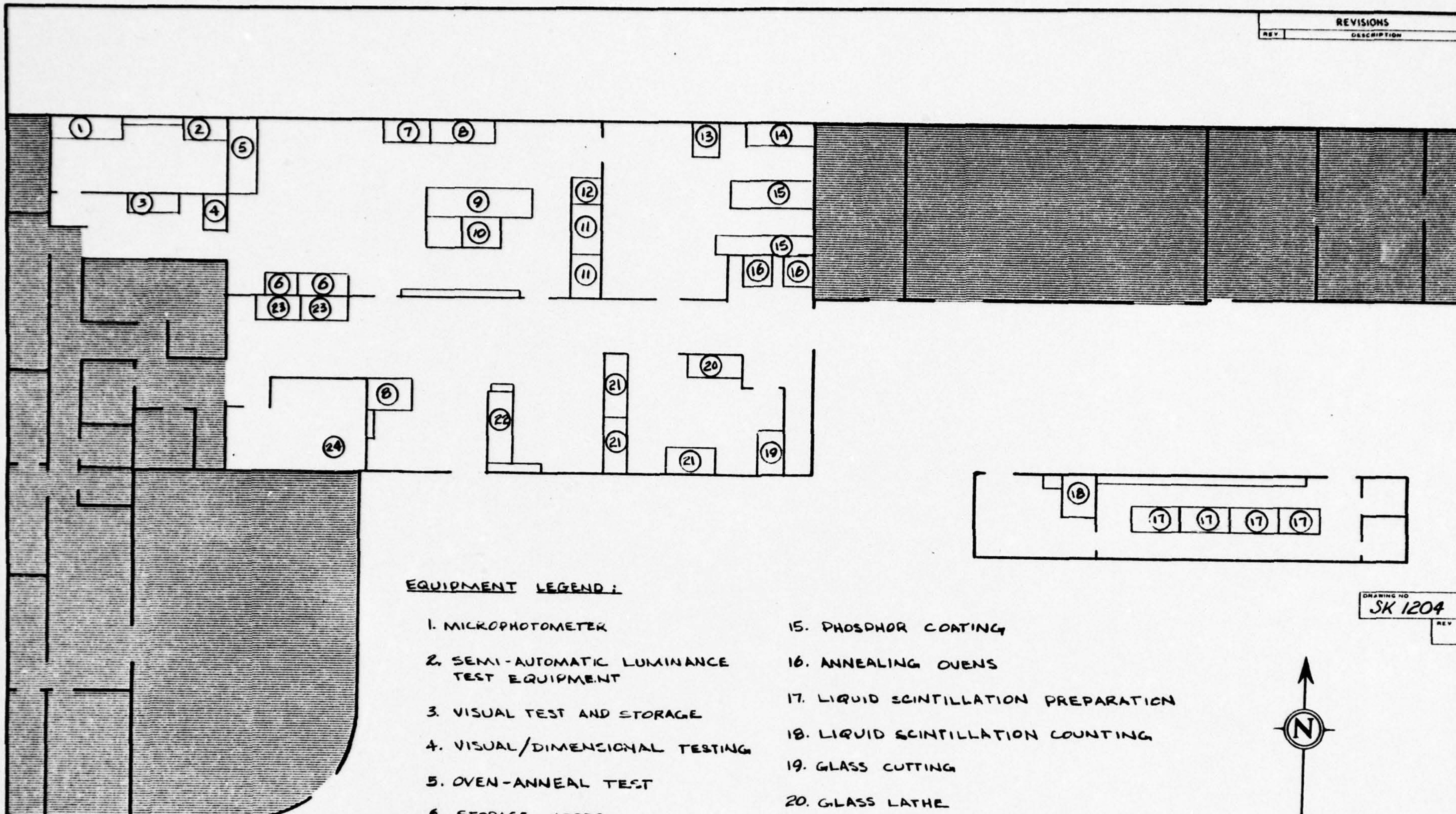
.XX ± .03
.X ± .1
ANGLES ± 0°-30'
HOLES PER
AND 10387
NEXT
ASSY
QTY

Fig. 18



EQUIPMENT LEGEND:

1. MICROPHOTOMETER
2. SEMI-AUTOMATIC LUMINANCE TEST EQUIPMENT
3. VISUAL TEST AND STORAGE
4. VISUAL/DIMENSIONAL TESTING
5. OVEN-ANNEAL TEST
6. STORAGE HOODS
7. TRITIUM HOOD
8. BENCH
9. 16-POSITION TRITIUM FILLING
10. 6-POSITION TRITIUM FILLING
11. AUXILIARY LASER SEALING
12. STORAGE OVEN
13. BAKING OVEN
14. SINK AND DRAIN
15. PHOSPHOR COATING
16. ANNEALING OVENS
17. LIQUID SCINTILLATION PREPARATION
18. LIQUID SCINTILLATION COUNTING
19. GLASS CUTTING
20. GLASS LATHE
21. GLASS FORMING
22. SHIPPING & RECEIVING
23. INCOMING INSPECTION
24. STORAGE

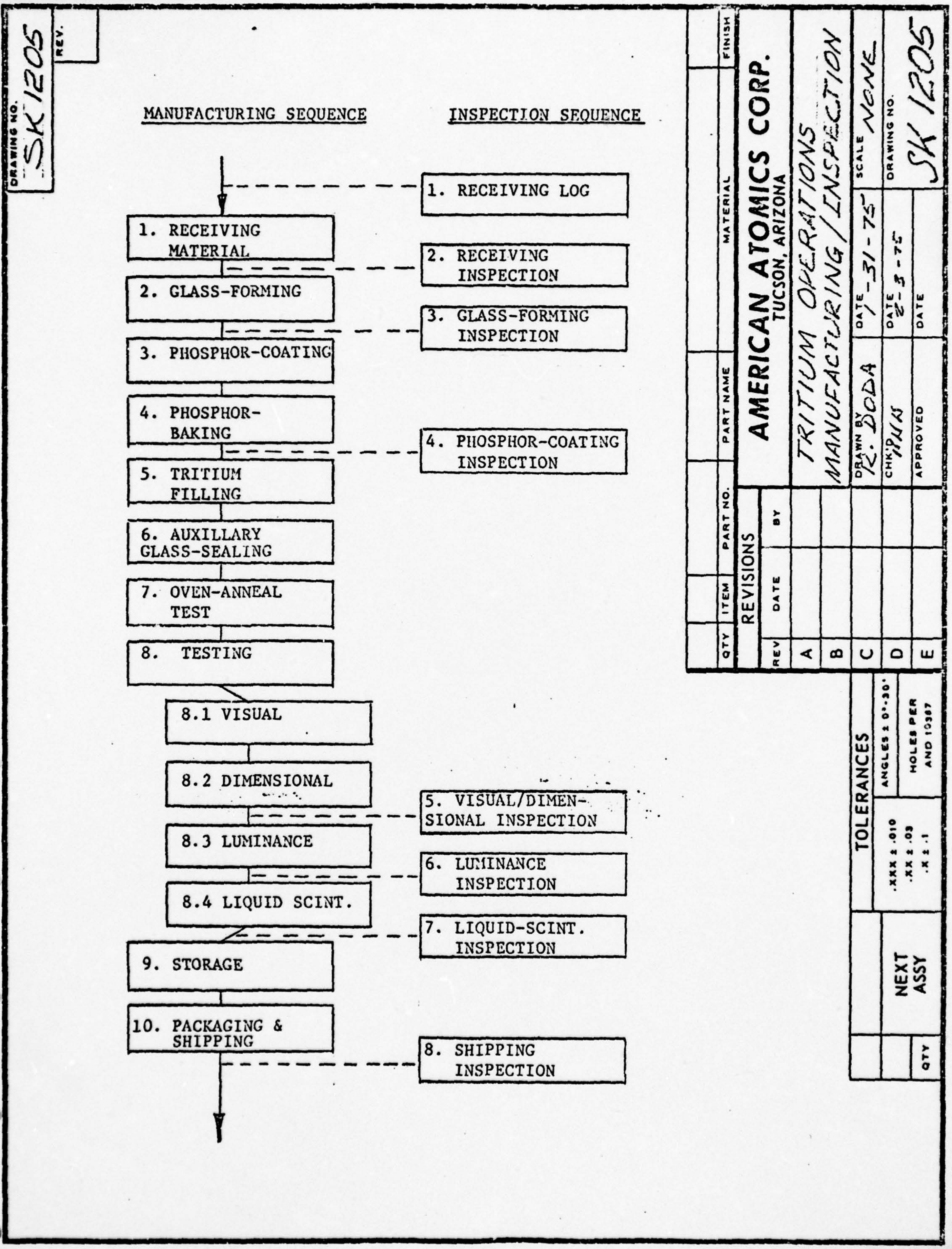
DRAWING NO SK 1204
REV

AMERICAN ATOMICS CORP.
TUCSON, ARIZONA

TRITIUM OPERATIONS

DRAWN R. DODA — DATE 1-20-75 — SCALE —
CHK'D — DATE
APPROVED NNA — DATE 1-20-75
DRAWING NO SK 1204

Fig. 19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INSPECTION SEQUENCE
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2. GLASS-FORMING
3. PHOSPHOR-COATING
4. PHOSPHOR-BAKING
5. TRITIUM FILLING
6. AUXILLARY GLASS-SEALING
7. OVEN-ANNEAL TEST
8. TESTING
8.1 VISUAL
8.2 DIMENSIONAL
8.3 LUMINANCE
8.4 LIQUID SCINT.
9. STORAGE
10. PACKAGING & SHIPPING
1. RECEIVING LOG
2. RECEIVING INSPECTION
3. GLASS-FORMING INSPECTION
4. PHOSPHOR-COATING INSPECTION
5. VISUAL/DIMENSIONAL INSPECTION
6. LUMINANCE INSPECTION
7. LIQUID-SCINT. INSPECTION
8. SHIPPING INSPECTION
QTY
ITEM
PART NO.
PART NAME
MATERIAL
FINISH
AMERICAN ATOMICS CORP.
TUCSON, ARIZONA
TRITIUM OPERATIONS
MANUFACTURING/INSPECTION
REVISIONS
REV
DATE
BY
A
B
C
D
E
DRAWN BY R. DODA
DATE 1-31-75
CHK'D MAS
DATE 2-3-75
APPROVED
DATE
SCALE NONE
DRAWING NO. SK 1205
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.X ± .1
ANGLES ± 0°-30'
HOLES PER AND 10387
NEXT ASSY
QTY

Fig. 20

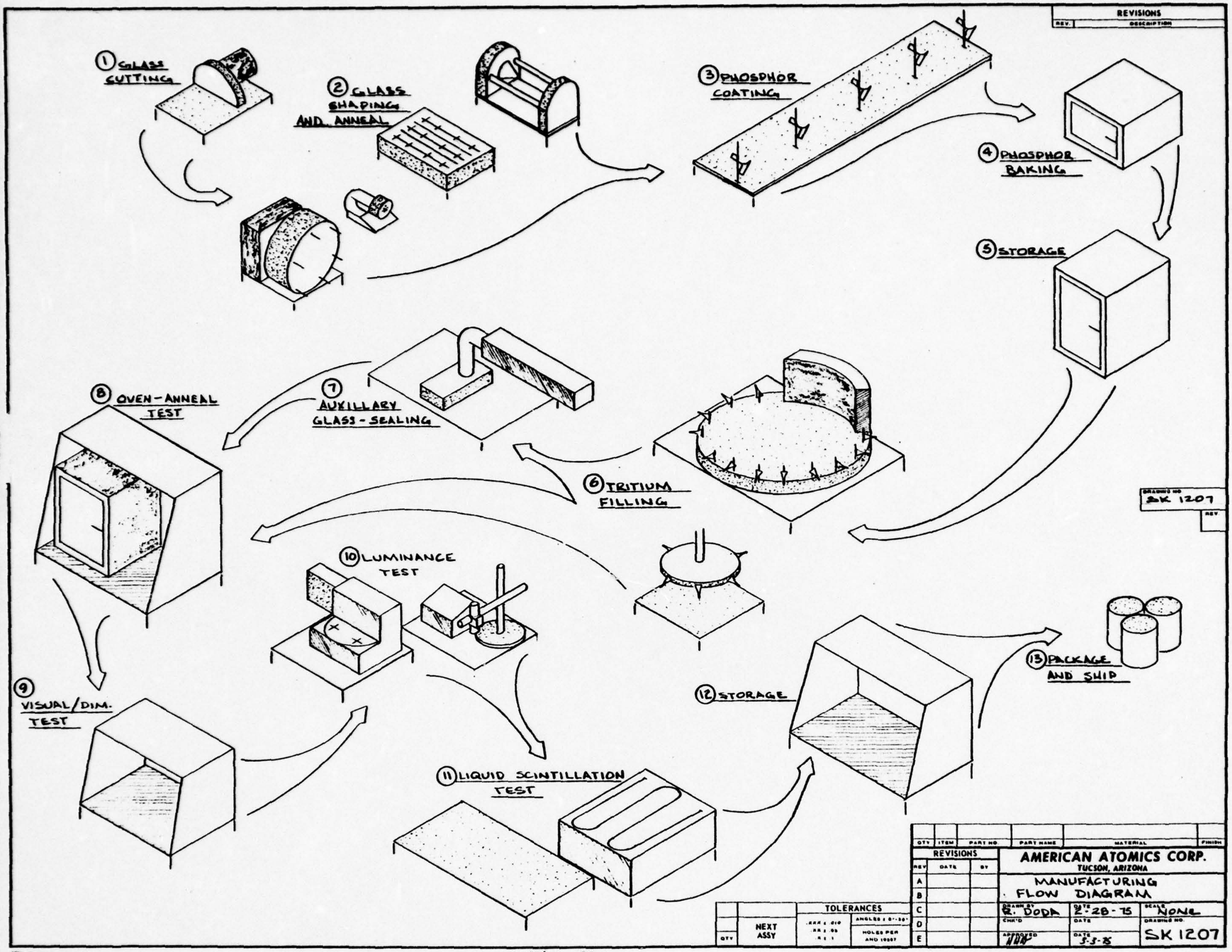
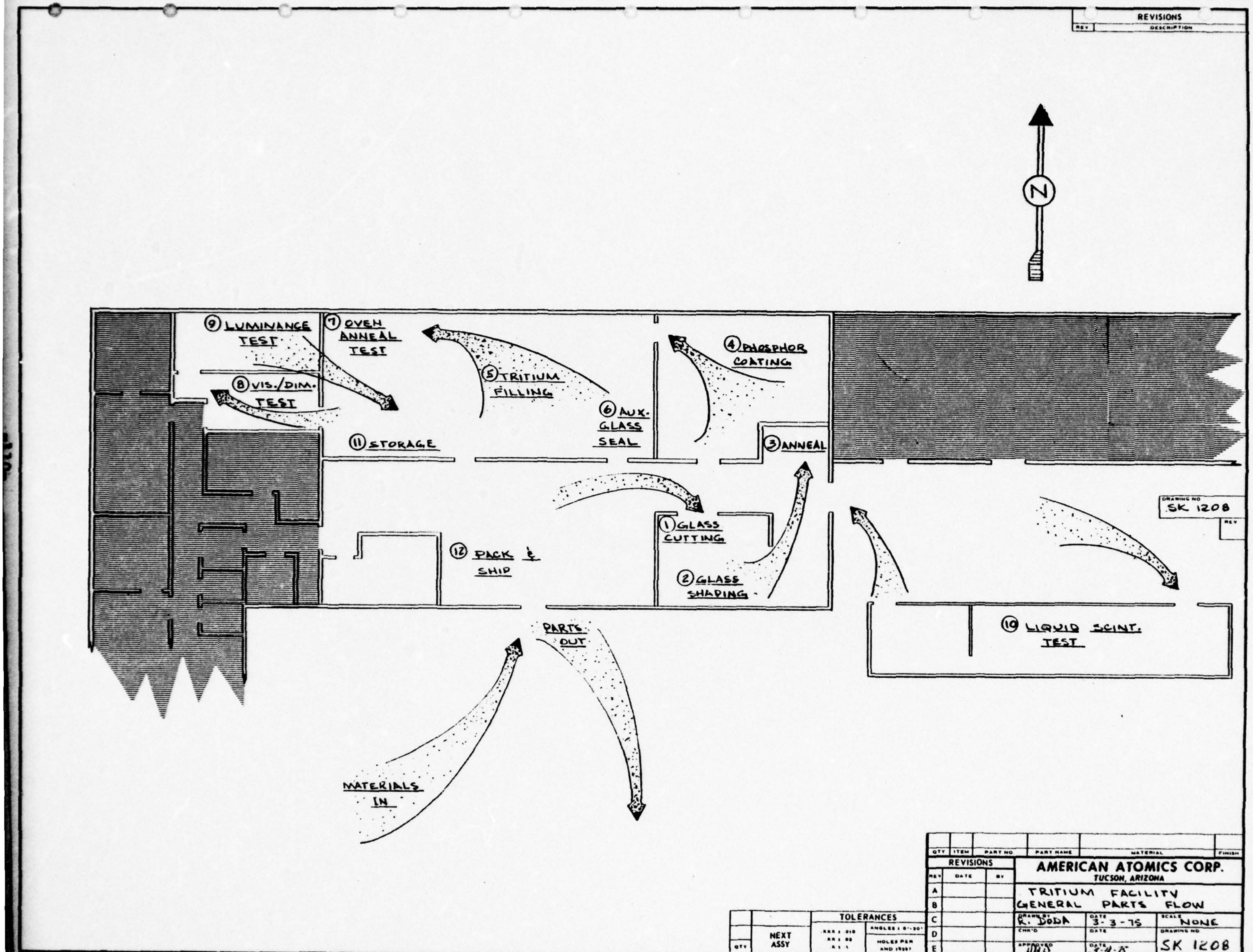

REVISIONS
REV. DESCRIPTION
① GLASS CUTTING
② GLASS SHAPING AND ANNEAL
③ PHOSPHOR COATING
④ PHOSPHOR BAKING
⑤ STORAGE
⑥ TRITIUM FILLING
⑦ AUXILLARY GLASS-SEALING
⑧ OVEN-ANNEAL TEST
⑨ VISUAL/DIM. TEST
⑩ LUMINANCE TEST
⑪ LIQUID SCINTILLATION TEST
⑫ STORAGE
⑬ PACKAGE AND SHIP
DRAWING NO. SK 1207
REV
QTY ITEM PART NO PART NAME MATERIAL FINISH
REVISIONS
REV DATE BY
A
B
C
D
E
AMERICAN ATOMICS CORP.
TUCSON, ARIZONA
MANUFACTURING FLOW DIAGRAM
DRAWN BY R. DODA DATE 2-28-75 SCALE NONE
CHK'D DATE DRAWING NO.
APPROVED DATE 3-3-75 SK 1207
TOLERANCES
NEXT ASSY
QTY
HOLES PER AND 10387

Fig. 21



REVISIONS
REV
DESCRIPTION
N
9 LUMINANCE TEST
7 OVEN ANNEAL TEST
8 VIS./DIM. TEST
5 TRITIUM FILLING
6 AUX. GLASS SEAL
4 PHOSPHOR COATING
3 ANNEAL
11 STORAGE
1 GLASS CUTTING
2 GLASS SHAPING
12 PACK & SHIP
PARTS OUT
MATERIALS IN
10 LIQUID SCINT. TEST
DRAWING NO
SK 1208
REV
QTY
ITEM
PART NO
PART NAME
MATERIAL
FINISH
REVISIONS
REV
DATE
BY
A
B
C
D
E
AMERICAN ATOMICS CORP.
TUCSON, ARIZONA
TRITIUM FACILITY
GENERAL PARTS FLOW
DRAWN BY
K. DODA
DATE
3-3-75
SCALE
NONE
CHK'D
DATE
DRAWING NO
APPROVED
DATE
3-4-75
SK 1208
TOLERANCES
NEXT ASSY
QTY

Fig. 22

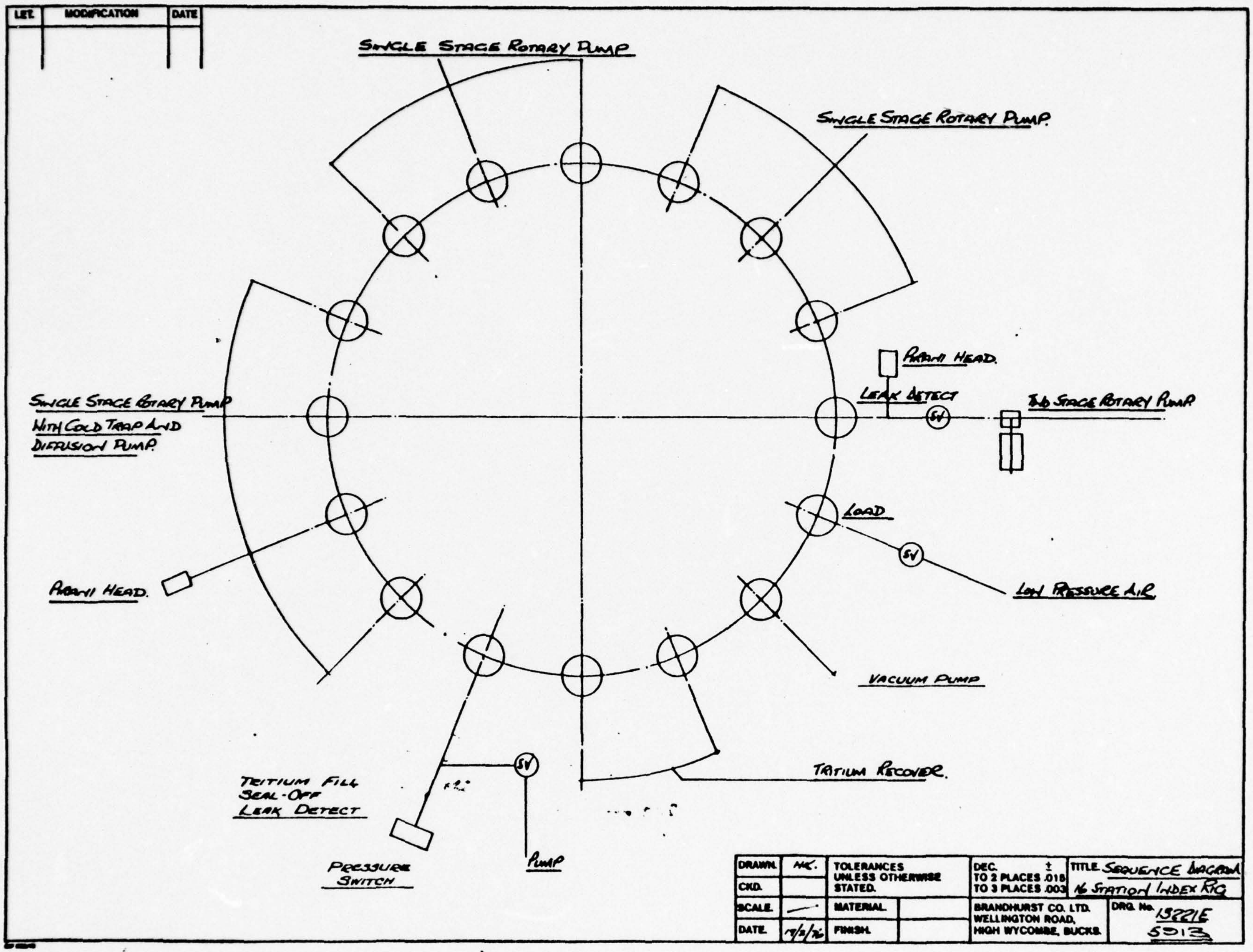
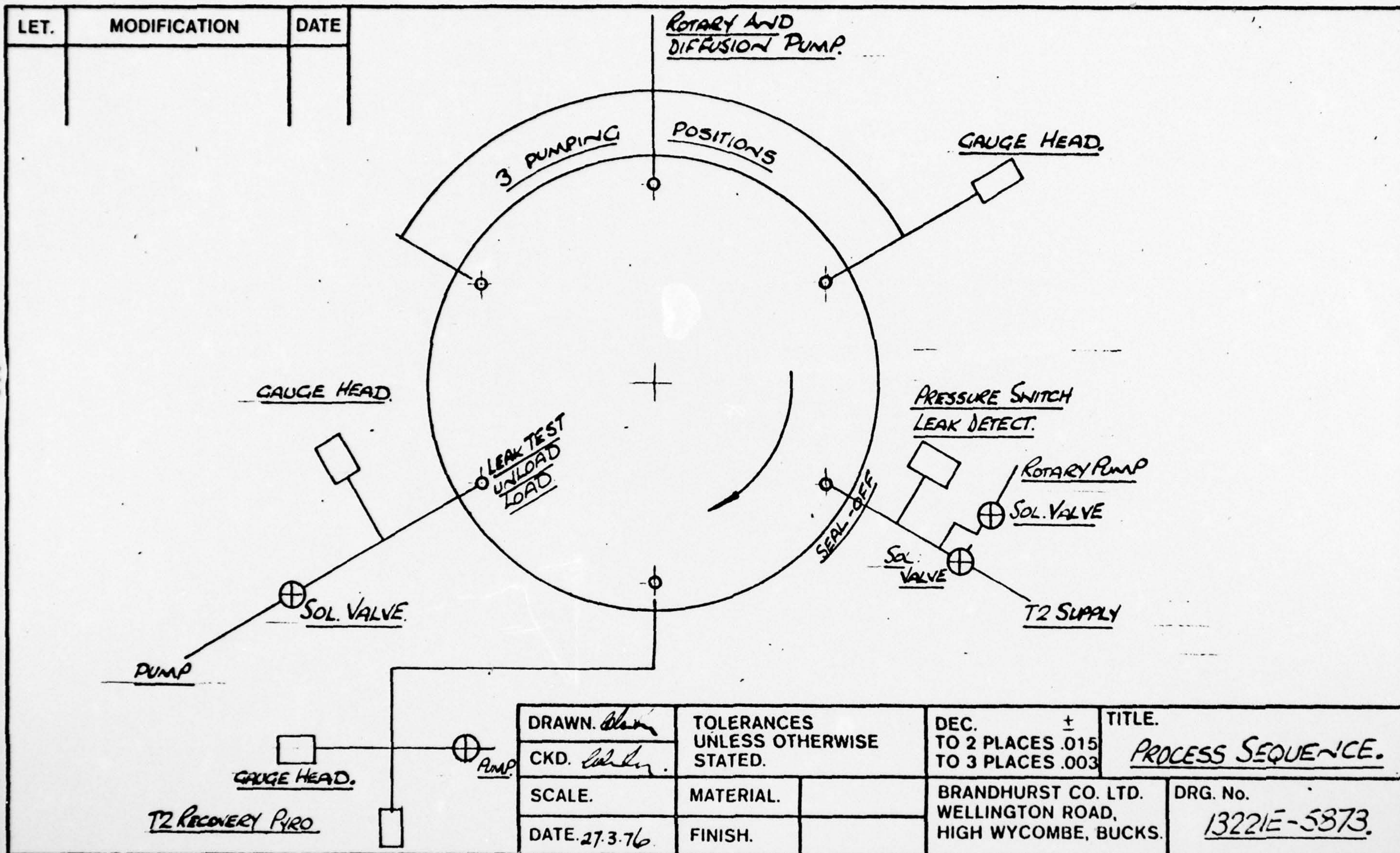

LET.
MODIFICATION
DATE
SINGLE STAGE ROTARY PUMP
SINGLE STAGE ROTARY PUMP.
PIRANI HEAD.
LEAK DETECT
SV
TWO STAGE ROTARY PUMP
SINGLE STAGE ROTARY PUMP
WITH COLD TRAP AND
DIFFUSION PUMP.
LOAD
SV
LOW PRESSURE AIR
PIRANI HEAD.
VACUUM PUMP
SV
TRITIUM RECOVER.
TRITIUM FILL
SEAL-OFF
LEAK DETECT
PUMP
PRESSURE
SWITCH
DRAWN. MC.
CKD.
SCALE.
DATE. 19/3/76
TOLERANCES UNLESS OTHERWISE STATED.
MATERIAL.
FINISH.
DEC. ± TO 2 PLACES .015 TO 3 PLACES .003
BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.
TITLE. SEQUENCE DIAGRAM 16 STATION INDEX RIG
DRG. No. 13221E 5513

Fig. 23


LET.
MODIFICATION
DATE
ROTARY AND DIFFUSION PUMP.
3 PUMPING POSITIONS
GAUGE HEAD.
GAUGE HEAD.
LEAK TEST
UNLOAD
LOAD
PRESSURE SWITCH
LEAK DETECT.
ROTARY PUMP
SOL. VALVE
SEAL-OFF
SOL. VALVE
T2 SUPPLY
SOL. VALVE.
PUMP
PUMP
GAUGE HEAD.
T2 RECOVERY PYRO
DRAWN.
CKD.
SCALE.
DATE. 27.3.76
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MATERIAL.
FINISH.
DEC. ±
TO 2 PLACES .015
TO 3 PLACES .003
TITLE.
PROCESS SEQUENCE.
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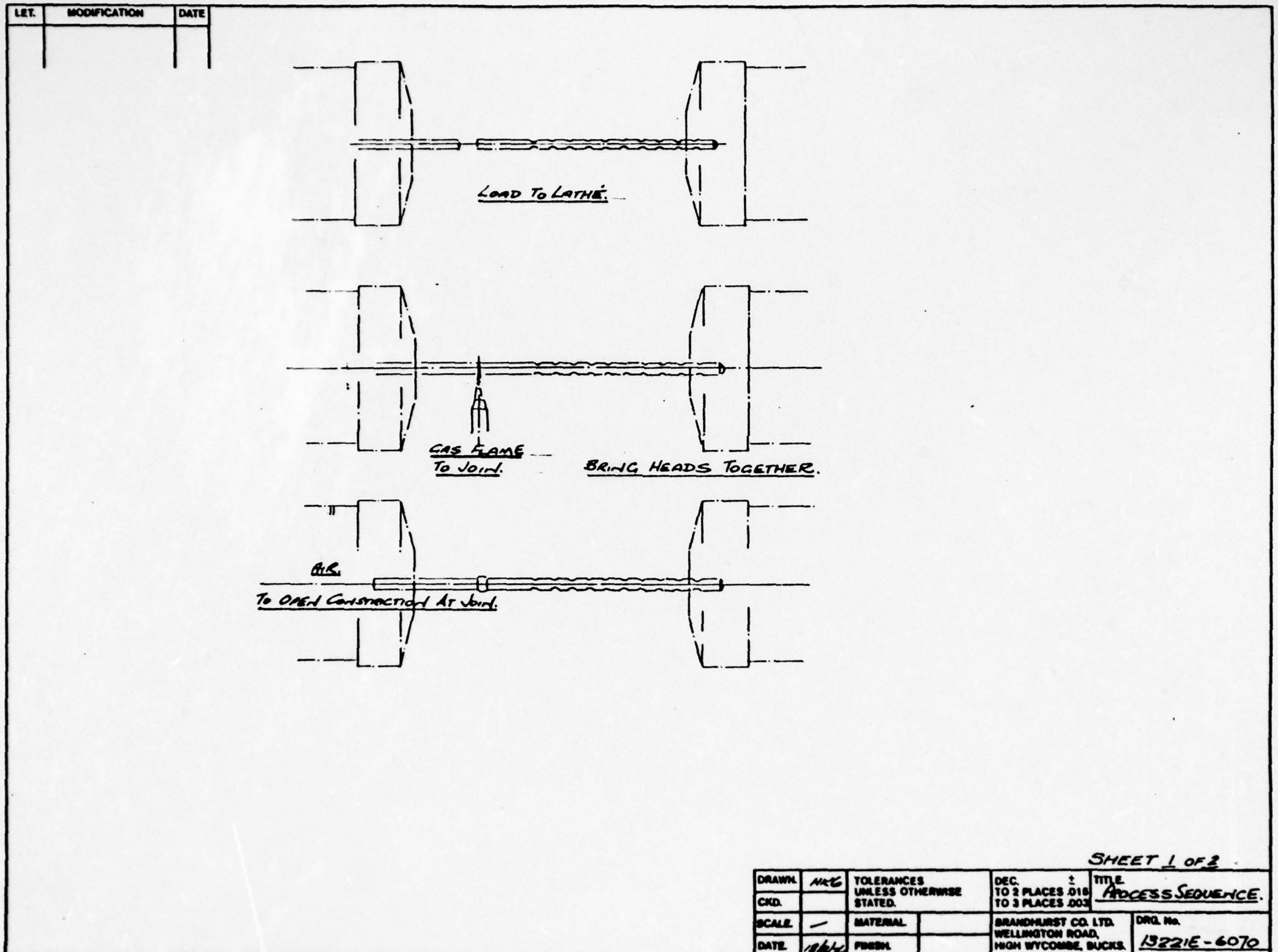
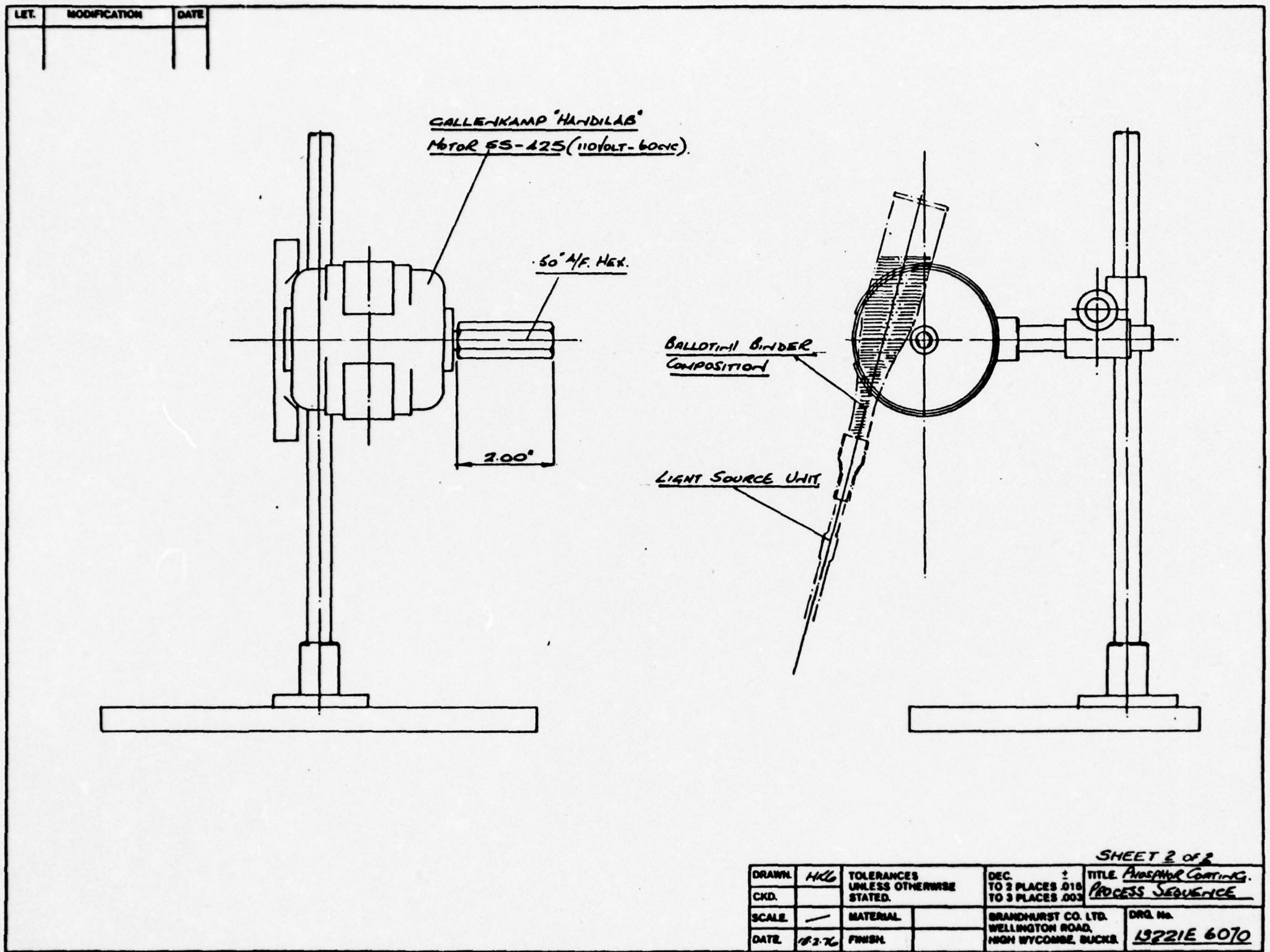
WELLINGTON ROAD,
HIGH WYCOMBE, BUCKS.
DRG. No.
1322IE-5873.

Fig. 24



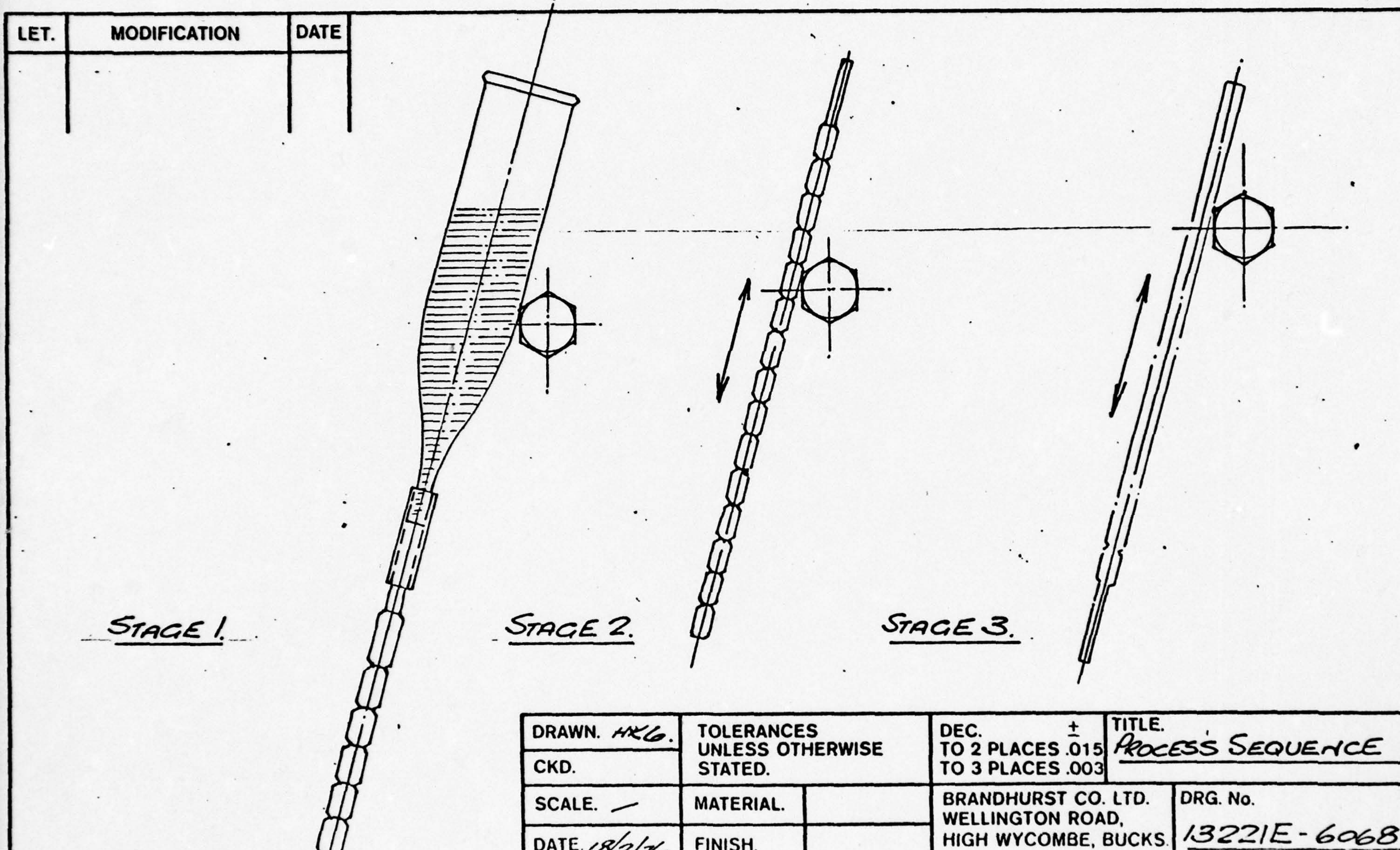
LET.
MODIFICATION
DATE
LOAD TO LATHE.
GAS FLAME
TO JOIN.
BRING HEADS TOGETHER.
AIR.
TO OPEN CONSTRICTION AT JOINT.
SHEET 1 OF 2
DRAWN.
CKD.
SCALE
DATE
TOLERANCES UNLESS OTHERWISE STATED.
MATERIAL
FINISH.
DEC. ± TO 2 PLACES .010 TO 3 PLACES .005
BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.
TITLE
PROCESS SEQUENCE.
DRG. No.
13221E-6070

Fig. 25



LET.
MODIFICATION
DATE
GALLENKAMP 'HANDILAB'
MOTOR SS-425 (110VOLT-60C/S).
.50" A/F. HEX.
2.00"
BALLOTINI BINDER
COMPOSITION
LIGHT SOURCE UNIT
SHEET 2 OF 2
DRAWN. HKG
CKD.
SCALE —
DATE 18.2.76
TOLERANCES UNLESS OTHERWISE STATED.
MATERIAL
FINISH.
DEC. ±
TO 2 PLACES .015
TO 3 PLACES .003
BRANDHURST CO. LTD.
WELLINGTON ROAD,
HIGH WYCOMBE, BUCKS.
TITLE PHOSPHOR COATING.
PROCESS SEQUENCE
DRG. No.
13221E 6070

Fig. 26


LET.
MODIFICATION
DATE
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STAGE 2.
STAGE 3.
DRAWN. HKG.
CKD.
SCALE. —
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TOLERANCES UNLESS OTHERWISE STATED.
MATERIAL.
FINISH.
DEC. ±
TO 2 PLACES .015
TO 3 PLACES .003
TITLE.
PROCESS SEQUENCE
BRANDHURST CO. LTD.
WELLINGTON ROAD,
HIGH WYCOMBE, BUCKS.
DRG. No.
13221E-6068

Fig. 27

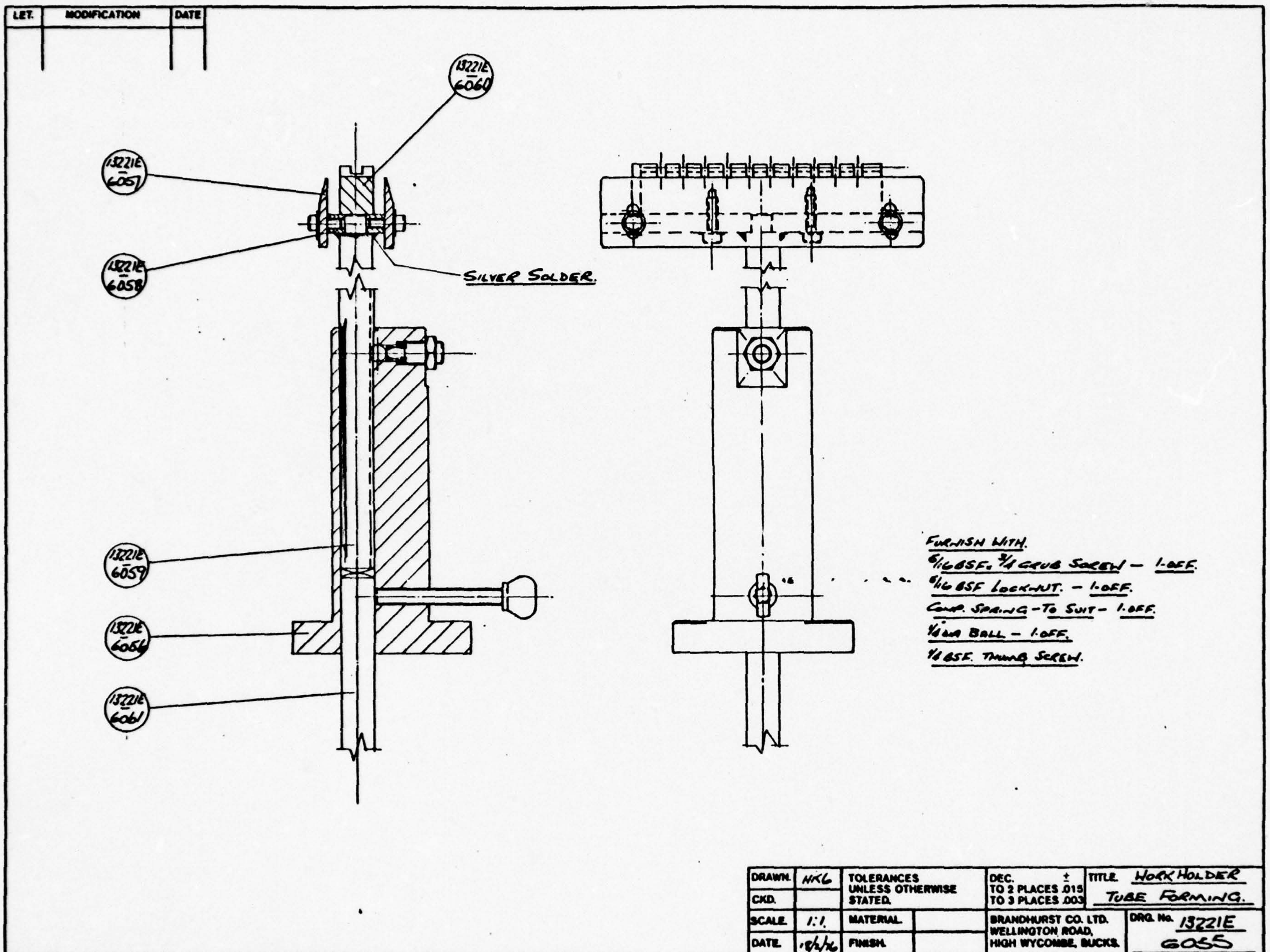

LET. MODIFICATION DATE
13221E 6060
13221E 6057
13221E 6058
SILVER SOLDER.
13221E 6059
13221E 6056
13221E 6061
FURNISH WITH.
5/16 BSF. 3/4 GRUB SCREW – 1.OFF.
5/16 BSF LOCKNUT. – 1.OFF.
COMP. SPRING – TO SUIT – 1.OFF.
1/4 DIA BALL – 1.OFF.
1/4 BSF. THUMB SCREW.
DRAWN. HKG
CKD.
SCALE 1:1
DATE 18/2/76
TOLERANCES UNLESS OTHERWISE STATED.
MATERIAL.
FINISH.
DEC. ± TO 2 PLACES .015 TO 3 PLACES .003
TITLE WORK HOLDER TUBE FORMING.
BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.
DRG. No. 13221E 6055

Fig. 28

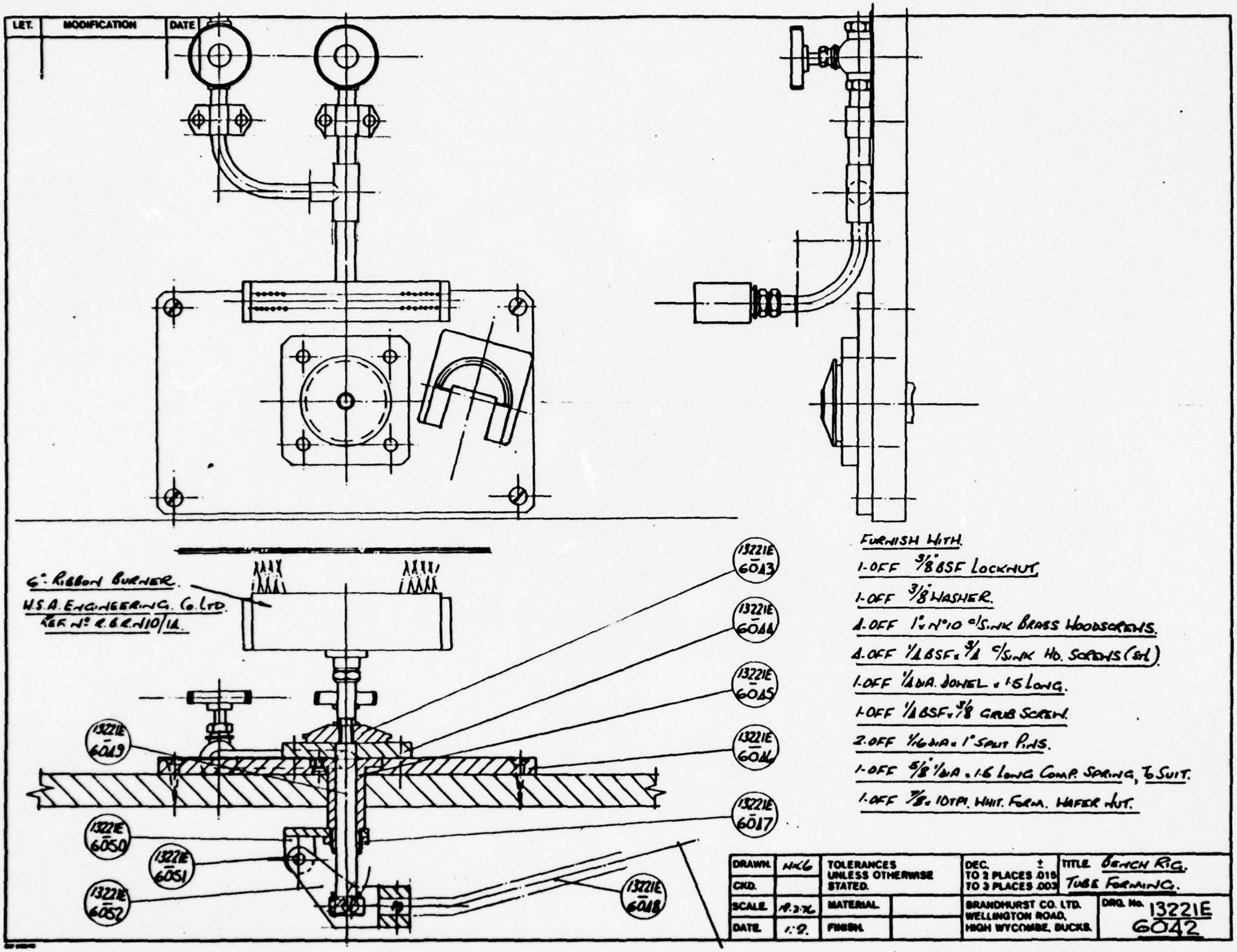
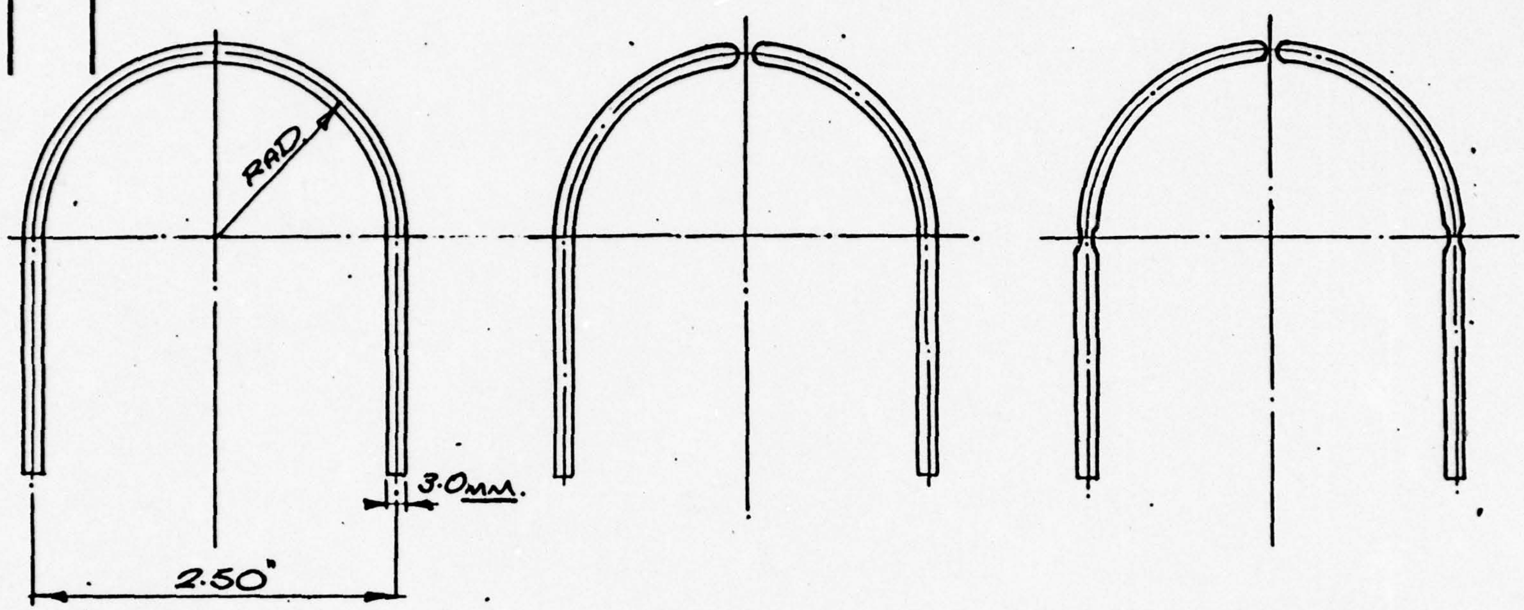

LET.
MODIFICATION
DATE
6" RIBBON BURNER.
H.S.A. ENGINEERING. Co. LTD.
REF. Nº R.B.R.N10/1A.
FURNISH WITH.
1-OFF 3/8" BSF LOCKNUT.
1-OFF 3/8" WASHER.
4-OFF 1" x Nº10 c/SINK BRASS WOODSCREWS.
4-OFF 1/4 BSF x 3/4 c/SINK HD. SCREWS (ST.)
1-OFF 1/4 DIA. DOWEL x 1.5 LONG.
1-OFF 1/4 BSF x 3/8 GRUB SCREW.
2-OFF 1/16 DIA x 1" SPLIT PINS.
1-OFF 5/8" I/DIA x 1.6 LONG COMP. SPRING, TO SUIT.
1-OFF 7/8 x 10 TPI. WHIT. FORM. WAFER NUT.
13221E 6013
13221E 6014
13221E 6015
13221E 6016
13221E 6017
13221E 6018
13221E 6019
13221E 6050
13221E 6051
13221E 6052
DRAWN. NKG
CKD.
SCALE 19.2.76
DATE 1:2.
TOLERANCES UNLESS OTHERWISE STATED.
MATERIAL
FINISH.
DEC. ± TO 2 PLACES .010 TO 3 PLACES .003
BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.
TITLE BENCH RIG. TUBE FORMING.
DRG. No. 13221E 6042

Fig. 29



STAGE 1.
FORM GLASS TUBE AROUND
FORMER AND CHECK AGAINST
ACCEPTANCE GAUGE.

STAGE 2.
SEPARATE AT CENTRE
AND CLOSE OFF

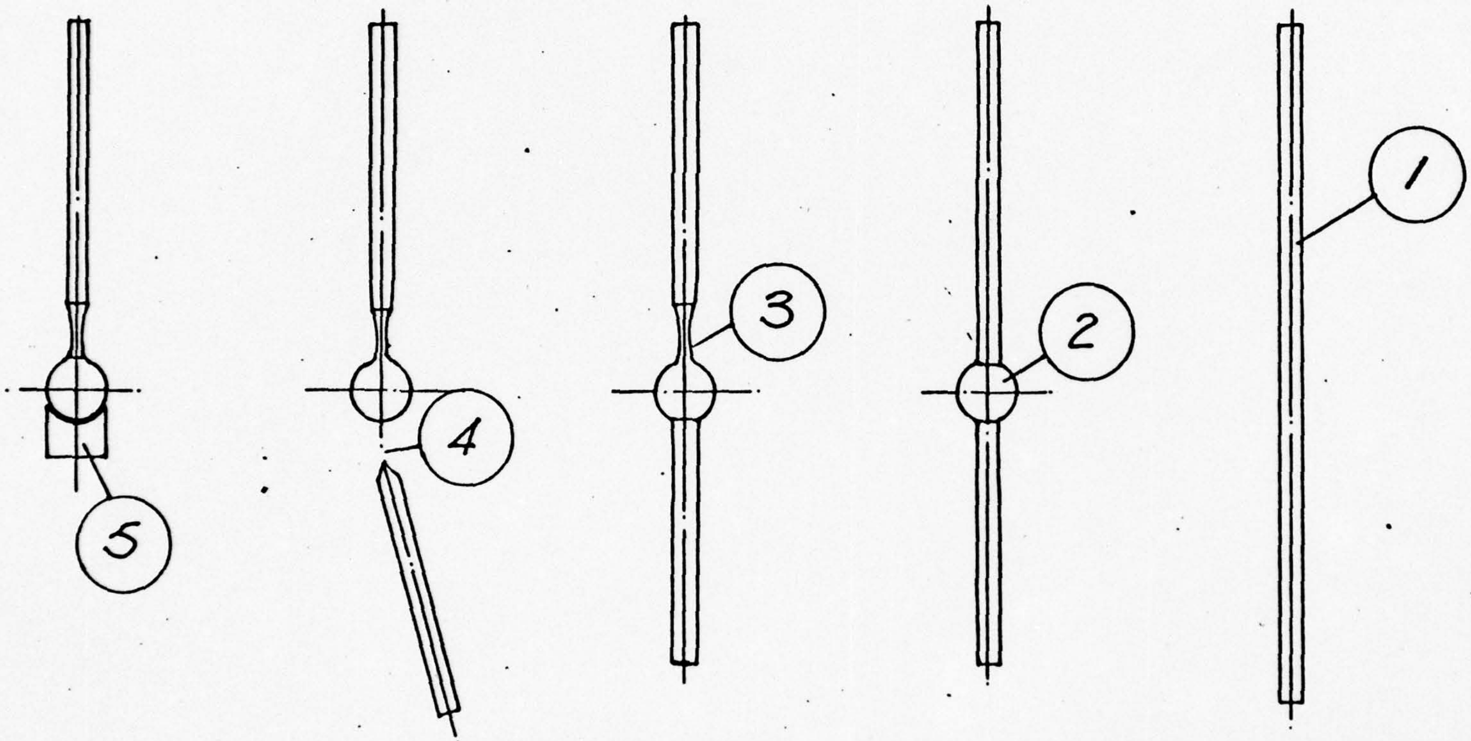
STAGE 3.
NECK DOWN AT
℄ OF RADIUS.

LET.	MODIFICATION	DATE

DRAWN. HKG	TOLERANCES UNLESS OTHERWISE STATED.	DEC. TO 2 PLACES ± .015 TO 3 PLACES ± .003	TITLE. PROCESS SEQUENCE
CKD.			
SCALE. —	MATERIAL.	BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.	DRG. No. 13221E-6067.
DATE. 18/2/76.	FINISH.		

Fig. 30

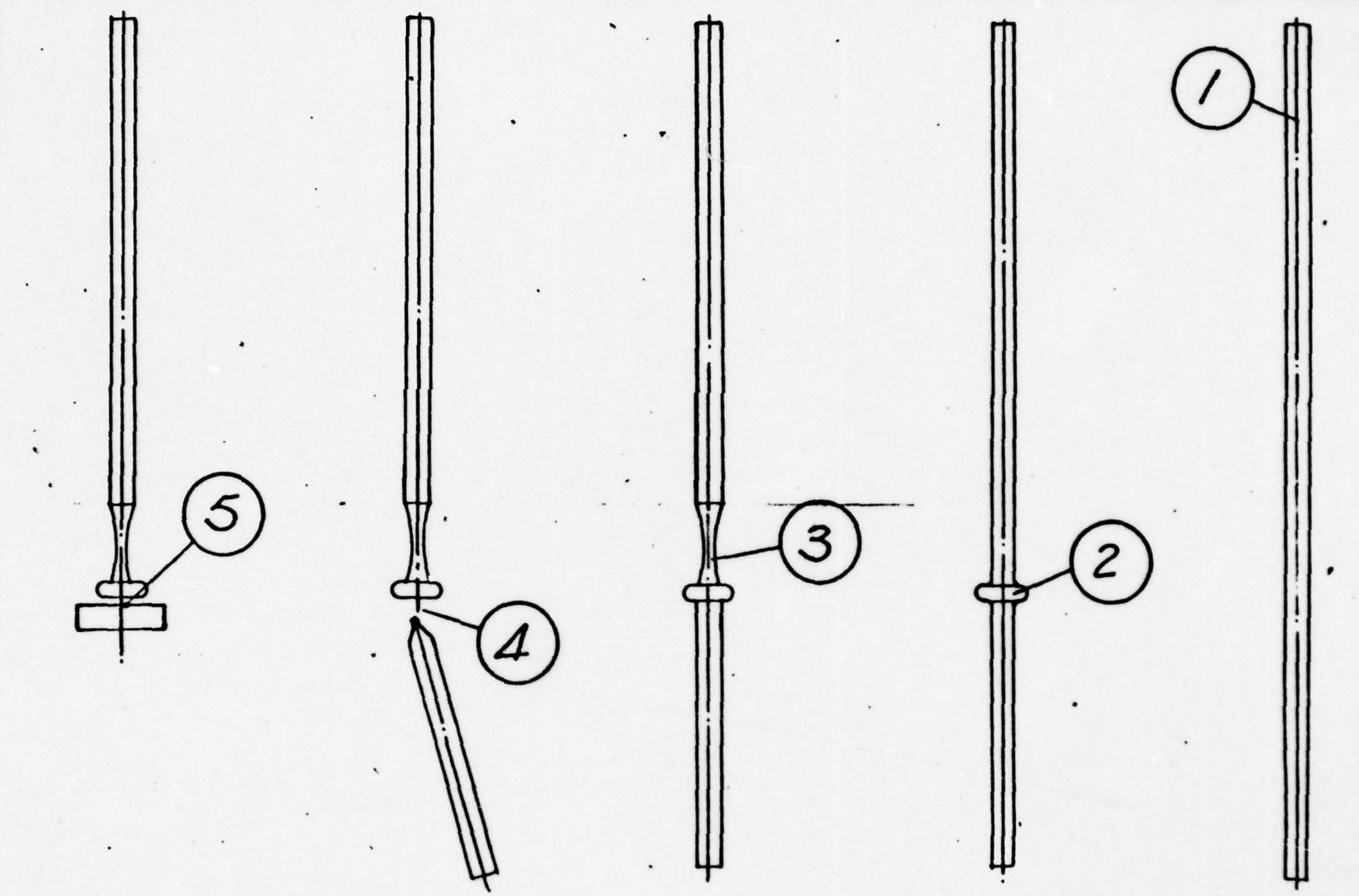
LET.	MODIFICATION	DATE



DRAWN. HKG	TOLERANCES UNLESS OTHERWISE STATED.	DEC. ± TO 2 PLACES .015 TO 3 PLACES .003	TITLE. PROCESS SEQUENCE
CKD.			
SCALE. —	MATERIAL.	BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.	DRG. No. 13221E-6069.
DATE. 18/2/76.	FINISH.		

Fig. 31

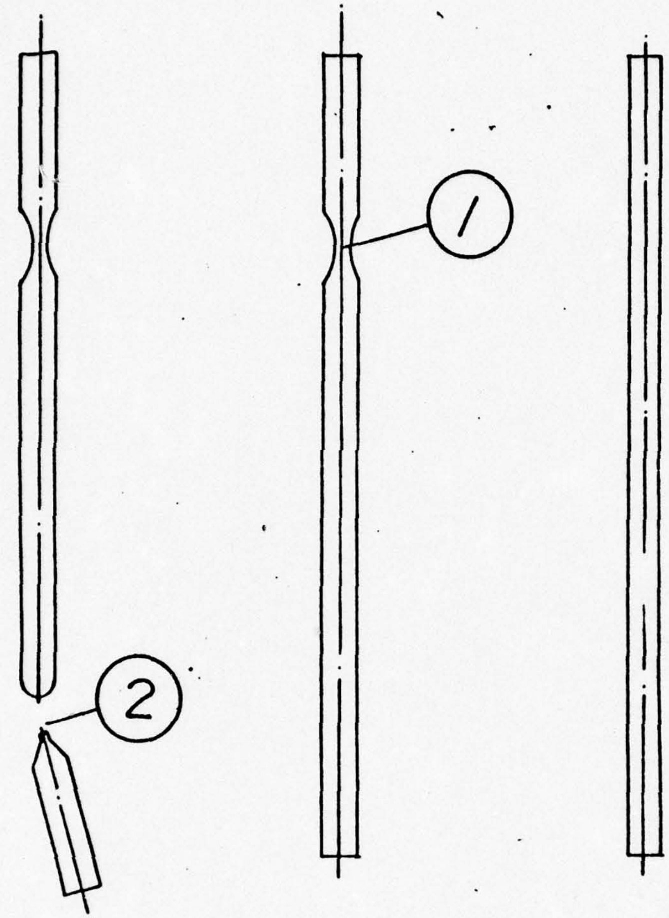
LET.	MODIFICATION	DATE



DRAWN. HKG	TOLERANCES UNLESS OTHERWISE STATED.		DEC. ± TO 2 PLACES .015 TO 3 PLACES .003	TITLE. PROCESS SEQUENC
CKD.				
SCALE. —	MATERIAL.		BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.	DRG. No. 13221E-6066
DATE. 18/2/76.	FINISH.			

Fig. 32

LET.	MODIFICATION	DATE



DRAWN. HKG	TOLERANCES UNLESS OTHERWISE STATED.		DEC. ± TO 2 PLACES .015 TO 3 PLACES .003	TITLE. PROCESS DIAGRAM
CKD.				
SCALE. —	MATERIAL.		BRANDHURST CO. LTD. WELLINGTON ROAD, HIGH WYCOMBE, BUCKS.	DRG. No. 13221E-6065
DATE. 18/2/76	FINISH.			

Fig. 33

APPENDIX B

EQUIPMENT SPECIFICATIONS - REPORT NO. 375/AA-48

CONTRACT NUMBER DAAK02-74-C-0147

NO.	ITEM DESCRIPTION	SPECIFICATIONS	UTILITIES
1.	Stainless Steel Hoods, Blickman E/2, Argonne Type, With Stands. (2 each)	24" x 60" x 40" High 36" x 96" x 40" High	115 VAC 60 Hz
2.	16-Position Rotary Index Filling Machine	Automatic Sequencing, 16 Heads, 10 Second Dwell Time, Tritium Supply and Pyros, Vacuum Pumping, Tritium Back-Filling, 360 Sources Per Hour	115 VAC, 60 Hz, 50 a, Gas - 5 psi, O_2 - 5 psi, Water - 1/4 G.P.M., Air-80 psi, LN_2 For Diffusion Pump
3.	6-Position Inverted Rotary Index Filling Machine	Semi-Automatic Sequencing, 6 Heads, Infinite Dwell Time, Tritium Supply and Pyros, Vacuum Pumping, Tritium Back-Filling, Source Cryogenic Cooling System 120 Sources Per hour, (30 Pressurized Sources Per Hour)	115 VAC, 60 Hz, 25 a, Gas - 5 psi, O_2 - 5 psi, Water - 1/4 G.P.M., LN_2 For Diffusion Pump and Dewar
4.	Glass-Working Machine, Pay Lamp Machinery Model MB-14	9-Head, Automatic Indexing, Dwell Time Sec.	220 VAC, 60 Hz, 3 Phase, 10 a, Gas - 5 psi, O_2 - 5 psi, Air - 80 psi
5.	Tube Constricting Machine Pay Lamp Machinery Model No. FD.	4-Burner Type, Automatic Indexing, Dwell Time - 6 Sec.	220 VAC, 60 Hz, 3 Phase, 2 a, Gas - 5 psi, O_2 - 5 psi
6.	Laser Sealing Equipment Coherent Model No. 42 CO_2 Laser Plus Accessories: 473 Beam Bender, RT-05 Reflector, LS-20 Lens, 205 Power Meter, 162 Gas Mixing System	CO_2-N_2-He, Wavelength - 10.6 μ, 50 Watts TEM_{oo} Continuous Power, Beam Dia. - 6.3 mm, Cavity Length - 1 meter, Polarization - Random	115 VAC, 60 Hz, 20 a, Water - 1 G.P.M., Water Pressure - 20 PSID, Temp.-70°F Max. Air - 80 psi

NO.	ITEM DESCRIPTION	SPECIFICATIONS	UTILITIES
7.	Photometric Equipment, Gamma Scientific Model 2400 MR Recording Scanning Microphotometer System Plus Accessories: 500 X-Y Recorder, 700-10A Photometric Microscope, 700-10-4A Microscope Objective, 700-10-63 Scanning Photometric Microscope Eyepiece, 700-10-70 Motor Drive, 700-10-3A Adjustable Microscope Stand, 700-3B Flexible Fiber Optic Probe, 2020-6 General Purpose Adapter, 2020-1A Photoptic Correction Filter, 2020-1 S-11 Photosurface End-On Photomultiplier Detector Assembly With 9' Cable, 220 Standard Lamp Source, 220-1A Luminance and Radiance Standard Head	BCD Output, 3-1/2 Digit Display, Photomultiplier High Voltage 300-1650 V, Time Constant .1 and 1.0 Second, Maximum Amplifier Sensitivity: Full Scale Reading With Less Than 1 Nanoamp Input	115 VAC 60 Hz
8.	Luminance Test Equipment and Accessories: 1980-OP Photo Research Pritchard Photometer, 1980-CDB Pritchard Photometer Control Console, WFL-10 Wide Field Lens, Jackson Index Table, Housing and Cabinet, Scientific Products No. BS1431 Lab Table	Sensitivity Range - 10^{-5} to 10^{7} Ft-L Full Scale, 7" Objective Lens, 6 Apertures, Viewing Field 1.9°, 5.9°, 11°, Spectral Response - 360 to 700 nm, Photoptic Filter, Time Constants - .02, .20, 2.0 Seconds, Index Table Variable Stepping Speed	Photometer: 115 VAC, 60 Hz, 20 w. Index Table: 115 VAC, 60 Hz, 1/4 HP, Vaccum Line
9.	Liquid Scintillation Equipment, Searle Analytic IsoCap/300 Table Top Liquid Scintillation System, Model No. 6868B	300 Sample Capacity, Automatic External Standard, Teletype With ASCII Paper Punch	115 VAC 60 Hz 12.5 a

EQUIPMENT SPECIFICATIONS - REPORT NO. 375/AA-48 (con't)

No.	ITEM DESCRIPTION	SPECIFICATIONS	UTILITIES
10.	He-Mass Spectrometer Leak Detector, Varian Model 925 Complete Plus Accessories: Helium Spray Probe, Calibrated Leak, Adapter Kit, Ion Source, O-Ring Kit	Sensitivity - 1×10^{-11} std. cc/sec., Manumatic Valve	115 VAC 60 Hz 20 a
11.	Tritium Monitors, Johnson Laboratories No. 955B (5 each)	Gamma Compensation, 10 to 10,000 $\mu Ci/m^3$, Four Ion Chambers - 5 Liters Each, Time Constants - 15 Seconds and 45 Seconds	115 VAC 60 Hz 100 w
12.	Glass-Annealing Furnaces, Gruenberg Model No. B120C16 With Floor Stands (2 each)	Temp. - 1200°F Max., Capacity - 1.6 Ft^3	220 VAC 3 Phase 3.5 kw
13.	Phosphor Baking Oven, Gruenbert Model No. B120C16 With Floor Stand and Barber-Coleman Controller	Temp. - 1200°F Max., Capacity - 1.6 Ft^3	220 VAC 3 Phase 3.5 kw
14.	Oven-Anneal Test Equipment, Gruenberg Model No. B120C16 With Barber-Coleman Indicating Programming Controller and Forced-Air Cooling	Temp. - 1200°F Max., Capacity - 1.6 Ft^3	220 VAC 3 Phase 3.5 kw
15.	Tube Storage Oven, Gruenberg Model No. ECO-15	Temp. - 450°F Max., Capacity - 20 Ft^3	220 VAC 3 Phase 9 kw
16.	Fiberglass Hoods, Hemco Mod. No. 20502 (2 ea)	59" x 30" x 59" High	115 VAC, 60 Hz
	Hemco Mod. No. 20501	59" x 30" x 59" High	115 VAC, 60 Hz
	Hemco Mod. No. 20301	35" x 30" x 59" High	115 VAC, 60 Hz
	Hemco Mod. No. 64502 Plus Table	45" x 24" x 28" High	115 VAC, 60 Hz
17.	Anemometer, Alnor Type 8500	Portable, Battery Operated, Range - 10 to 2000 Linear fpm	N/A

EQUIPMENT SPECIFICATIONS - REPORT NO. 375/AA-48 (con't)

NO.	ITEM DESCRIPTION	SPECIFICATIONS	UTILITIES
18.	Glassworking Lathe, Bethlehem Model GL-25A, GL-25B Quickload Chuck, LR2A Burner Assembly, GL-25 Torch Holder	Length - 33", Height - 10-1/4", Width - 14", Distance Between Spindles - 19", Bore - 1-3/8", Swing - 7"	115 VAC 60 Hz 1/12 HP
19.	Lab Carts, VWR No. 19758 (4 each)	Stainless Steel, 4" Castors	N/A
20.	Stereomicroscope With Starlite Illuminator, AO Model 42, AO Model 363V	10 X and 20 X	115 VAC 60 Hz
21.	Bench Burner, VWR No. 18321-004	Height - 9", Base Dia. - 6"	Oxygen and Natural Gas - 1/4 - 5 psi
22.	Glass Tube Storage Rack, VWR No. 32842-426	14" x 14" x 52" Long With Compartments	N/A
23.	Lab Benches Assorted Sizes (18 ea) With Kemshield Tops, VWR	Assorted Sizes	N/A
24.	Phosphor Coating Equipment, VWR No. 58950-253 Stirrer, No. 21572-556 Clamp Holder, No. 60110-062 Support Stand (6 ea)	200-5000 rpm	115 VAC 60 Hz 1/100 HP
25.	Lab Chairs, Assorted Sizes (19 ea) Kewanee	Assorted	N/A
26.	Vacuum Pump, Welch No. 1376B	Two-Stage, 300 Liters Per Min	115 VAC 60 Hz
27.	Vacuum Manipulators, Labtron Model LAB-69	Pencil Size, Finger Release, Metal Tip Sizes - .5 to 1.0 mm	Vacuum Supply
28.	Laser Tooling, Non-Rotating Sealing Device Bodine Gearmotor No. 541, Speed Control, and Cable	Special Cams, Speed - 0 to 288 rpm, Fixture Adjustments	115 VAC 60 Hz 1/50 HP
29.	Abrasive Glass Saw, Felker Model No. 11-B	Diamond Edge Blade - 8", Motor Pulley - 063 Spindle Pulley - 005 Motor - 1/2 HP	115 VAC 60 Hz Water - 2 G.P.M.

EQUIPMENT SPECIFICATIONS - REPORT NO. 375/AA-48 (con't)

NO.	ITEM DESCRIPTION	SPECIFICATIONS	UTILITIES
30.	Tritium Exhaust Blowers (3 ea)	1500 cfm 8000 cfm 11000 cfm	220 VAC 60 Hz 3 Phase
31.	Special Tooling	-	-
32.	Special Mountings	-	-
33.	Small Equipment and Supplies	-	-
34.	Liquid Nitrogen Containers		

APPENDIX C

Tritium Venting Rate from Tritium Light Source Facility

I. Tritium Release Rate Calculation

In the production of tritium light sources, two operations which vent tritium will have to be exhausted. These operations are: source filling and oven anneal testing. Both are conducted in hoods having a face velocity of approximately 200 linear ft./minute.

Tritium releases occurring in the source filling operation will be due to residual gas exhaust and accidental source leakage. The residual gas exhaust is due to the unrecoverable tritium left in the filling system after the source is sealed. The amount of gas exhausted is thus dependent on the residual system pressure and the volume of the system and filling stub containing tritium. It will be assumed that all the sources filled will contain 0.060 Ci of tritium. This is a larger value than the average will provide, giving a conservative release estimate. In this case, the pressure is 0.5mm Hg and the volume is 0.78cc. the gas volume is converted to activity (2.6 Ci/cc at STP) and it is assumed that 300 sources per hour are filled. The residual release rate is then determined to be 0.366 Ci/hr.

For the case of accidental leakage, it is assumed that the whole volume of tritium open to the source at filling pressure is vented. This volume is 1.26cc and the pressure is 270mm Hg. The gas volume is converted to activity and the source activity, which is also released, is added. This gives a tritium loss of 1.12 Ci/leak. It is assumed, on the basis of experience, that one source per hour will leak. This gives a total tritium release rate of 1.49 Ci/hr. for the source

filling operation.

After being filled, it is assumed that all the sources produced in one hour are placed in the oven for annealing and testing. Experience has shown that approximately 5% of the tubes leak while in the oven, providing for a release rate of 0.90 Ci/hr.

II. Down Wind Ground Level Concentration Calculation

Although the systems are on two separate stacks, the assumption will be made that the ground cloud originates from a point source. This assumption provides a conservative estimate for the maximum total concentration because in actuality the maximum concentration from each source will not occur at a single point. The actual concentration will thus be less than the sum of the two sources.

Using a Gaussian distribution model, the maximum ground level concentration is given by

$$X = \frac{\sigma_z}{\sigma_y} \frac{2Q}{\pi h^2 e U} \qquad (2\text{-}1)$$

Where X is the concentration of gaseous effluent, σ_z and σ_y are the standard deviations of the distribution of material in a plume in the Z-plane and y-plane respectively, Q is the effluent emission rate, h is the effective stack height, and U is the wind velocity. EQ. (2-1) is only valid for neutral atmospheric conditions. These conditions generally characterize the area considered, allowing EQ. (2-1) to become a valid model.

For the case of a nonbuoyant source whose plume rise is given by 1.5 d(W/U) and for $\sigma_z / \sigma_y \cong$ 0.5 (for neutral conditions) EQ. (2-1)

(2-1) G. A. Briggs, Plume Rise, USAEC Division of Technical Information TID-25075, April, 1970.

becomes

$$X = 0.01 \quad \frac{Q}{Wr\ h_s} \qquad (2\text{-}2)$$

Where W is the stack-gas efflux velocity, r is the inside stack radius, d is the inside stack diameter, and h_s is the actual stack height. The wind velocity that gives the maximum concentration is called the critical velocity (U_c) and is given by

$$U_c + 3W \quad \frac{r}{h_s} \qquad (2\text{-}3)$$

III. Source Filling System

The source filling system air is exhausted through a 12 inch diameter stack which is 40 ft. high. The air flow rate is 4000 CFM, giving an efflux velocity (W) of $3.056\text{x}10^5$ ft./hr. Using EQ. (2-2), the maximum ground level concentration is calculated:

$$X = 0.01 \quad \frac{1.49}{(3.056\text{x}10^5)\ (.5)\ (35)}$$

$$= 2.78\text{x}10^{-9} \ \frac{Ci}{Ft^3}$$

$$X = 7.87\text{x}10^{-11}\ Ci/m^3$$

the critical wind velocity at which this concentration occurs is given by EQ. (2-3),

$$U_c = 3(3.056\text{x}10^5) \quad \frac{(.5)}{40\ (5280)}$$

$$= 2.17 \text{ mph}$$

Oven Anneal Test Facility

The oven anneal test facility vents through a 10 inch diameter stack which is 35 ft. high. The flow rate of air through this stack is 2000 CFM, providing an efflux velocity of $2.200\text{x}10^5$ ft./hr. Using EQ(2.2), the down

wind ground level concentration is

$$X = 0.01 \quad \frac{0.09}{(2.200\text{x}10^5)(.42)(35)}$$

$$= 2.80\text{x}10^{-9} \quad \frac{\text{Ci}}{\text{Ft}^3}$$

$$X = 7.93\text{x}10^{-11} \quad \frac{\text{Ci}}{\text{m}^3}$$

The critical wind velocity at which this concentration occurs is given by EQ. (2-3) as

$$U_c = 3(2.200\text{x}10^5) \quad \frac{(.42)}{35(5280)}$$

$$= 1.50 \text{ MPH}$$

IV. Discussion

The sum of the maximum concentrations resulting from the stacks is $1.58\text{x}10^{-10}$ Ci/m^3. This value represents an upper limit of ground concentration at the operating conditions specified for two reasons: 1) The critical wind velocity was calculated to be different for each stack and it is incomprehensible that the wind velocity could vary that greatly in the distance between the two stacks, and 2) because the stacks are of different heights, the maximum concentrations will occur at different points. The concentration limit of tritium in air in an unrestricted area is $2\text{x}10^{-7}$ Ci/m^3. Thus, the obtained value of $1.58\text{x}10^{-10}$ Ci/m^3, which is more than a realistic estimate, is well within allowable limits.

APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Cobalt (27)	Co 57	S	3×10^{-6}	2×10^{-2}	1×10^{-7}	5×10^{-4}
		I	2×10^{-7}	1×10^{-2}	6×10^{-9}	4×10^{-4}
	Co 58m	S	2×10^{-5}	8×10^{-2}	6×10^{-7}	3×10^{-3}
		I	9×10^{-6}	6×10^{-2}	3×10^{-7}	2×10^{-3}
	Co 58	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-8}	3×10^{-3}	2×10^{-9}	9×10^{-5}
	Co 60	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
		I	9×10^{-9}	1×10^{-3}	3×10^{-10}	3×10^{-5}
Copper (29)	Cu 64	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	3×10^{-4}
		I	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
Curium (96)	Cm 242	S	1×10^{-10}	7×10^{-4}	4×10^{-12}	2×10^{-5}
		* I	2×10^{-10}	7×10^{-4}	6×10^{-12}	2×10^{-5}
	Cm 243	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	5×10^{-6}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	2×10^{-5}
	Cm 244	S	9×10^{-12}	2×10^{-4}	3×10^{-13}	7×10^{-6}
		I	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
	Cm 245	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 246	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 247	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	6×10^{-4}	4×10^{-12}	2×10^{-5}
	Cm 248	S	6×10^{-13}	1×10^{-5}	2×10^{-14}	4×10^{-7}
		I	1×10^{-11}	4×10^{-5}	4×10^{-13}	1×10^{-6}
	Cm 249	S	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
		I	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
Dysprosium (66)	Dy 165	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	7×10^{-8}	4×10^{-4}
	Dy 166	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
Einsteinium (99)	Es 253	S	8×10^{-10}	7×10^{-4}	3×10^{-11}	2×10^{-5}
		I	6×10^{-10}	7×10^{-4}	2×10^{-11}	2×10^{-5}
	Es 254m	S	5×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
		I	6×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
	Es 254	S	2×10^{-11}	4×10^{-4}	6×10^{-13}	1×10^{-5}
		I	1×10^{-10}	4×10^{-4}	4×10^{-12}	1×10^{-5}
	Es 255	S	5×10^{-10}	8×10^{-4}	2×10^{-11}	3×10^{-5}
		I	4×10^{-10}	8×10^{-4}	1×10^{-11}	3×10^{-5}
Erbium (68)	Er 169	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	4×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	Er 171	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Europium (63)	Eu 152	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	(T/2 = 9.2 hrs)	I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Eu 152	S	1×10^{-8}	2×10^{-3}	4×10^{-10}	8×10^{-5}
	(T/2 = 13 yrs)	I	2×10^{-8}	2×10^{-3}	6×10^{-10}	8×10^{-5}
	Eu 154	S	4×10^{-9}	6×10^{-4}	1×10^{-10}	2×10^{-5}
		I	7×10^{-9}	6×10^{-4}	2×10^{-10}	2×10^{-5}
	Eu 155	S	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
		I	7×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Fermium (100)	Fm 254	S	6×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
		I	7×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
	Fm 255	S	2×10^{-8}	1×10^{-3}	6×10^{-10}	3×10^{-5}
		I	1×10^{-8}	1×10^{-3}	4×10^{-10}	3×10^{-5}
	Fm 256	S	3×10^{-9}	3×10^{-5}	1×10^{-10}	9×10^{-7}
		I	2×10^{-9}	3×10^{-5}	6×10^{-11}	9×10^{-7}
Fluorine (9)	F 18	S	5×10^{-6}	2×10^{-2}	2×10^{-7}	8×10^{-4}
		I	3×10^{-6}	1×10^{-2}	9×10^{-8}	5×10^{-4}
Gadolinium (64)	Gd 153	S	2×10^{-7}	6×10^{-3}	8×10^{-9}	2×10^{-4}
		I	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
	Gd 159	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Gallium (31)	Ga 72	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Germanium (32)	Ge 71	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	6×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
Gold (79)	Au 196	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	6×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
	Au 198	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Au 199	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	8×10^{-7}	4×10^{-3}	3×10^{-8}	2×10^{-4}
Hafnium (72)	Hf 181	S	4×10^{-8}	2×10^{-3}	1×10^{-9}	7×10^{-5}
		I	7×10^{-8}	2×10^{-3}	3×10^{-9}	7×10^{-5}
Holmium (67)	Ho 166	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
Hydrogen (1)	H3	S	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		I	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		Sub	2×10^{-3}		4×10^{-5}	
Indium (49)	In 113m	S	8×10^{-6}	4×10^{-2}	3×10^{-7}	1×10^{-3}
		I	7×10^{-6}	4×10^{-2}	2×10^{-7}	1×10^{-3}
	In 114m	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	2×10^{-8}	5×10^{-4}	7×10^{-10}	2×10^{-5}
	In 115m	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	4×10^{-4}
	In 115	S	2×10^{-7}	3×10^{-3}	9×10^{-9}	9×10^{-5}
		I	3×10^{-8}	3×10^{-3}	1×10^{-9}	9×10^{-5}
Iodine (53)	I 125	S	5×10^{-9}	4×10^{-5}	8×10^{-11}	2×10^{-7}
		I	2×10^{-7}	6×10^{-3}	6×10^{-9}	2×10^{-4}
	I 126	S	8×10^{-9}	5×10^{-5}	9×10^{-11}	3×10^{-7}
		I	3×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	I 129	S	2×10^{-9}	1×10^{-5}	2×10^{-11}	6×10^{-8}
		I	7×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}
	I 131	S	9×10^{-9}	6×10^{-5}	1×10^{-10}	3×10^{-7}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	I 132	S	2×10^{-7}	2×10^{-3}	3×10^{-9}	8×10^{-6}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	I 133	S	3×10^{-8}	2×10^{-4}	4×10^{-10}	1×10^{-6}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
	I 134	S	5×10^{-7}	4×10^{-3}	6×10^{-9}	2×10^{-5}

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APPENDIX D

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